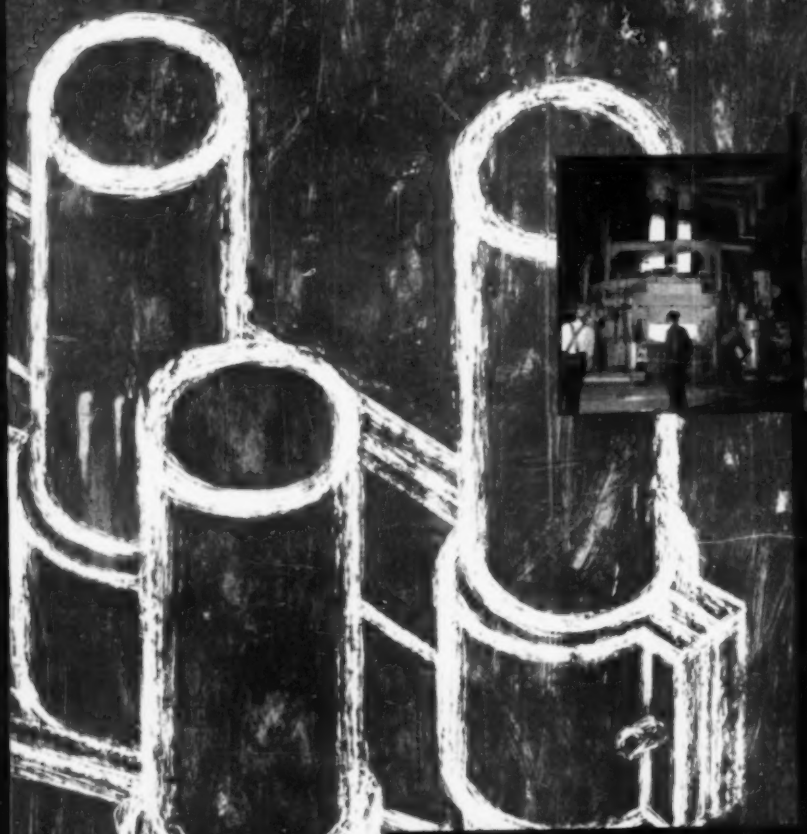
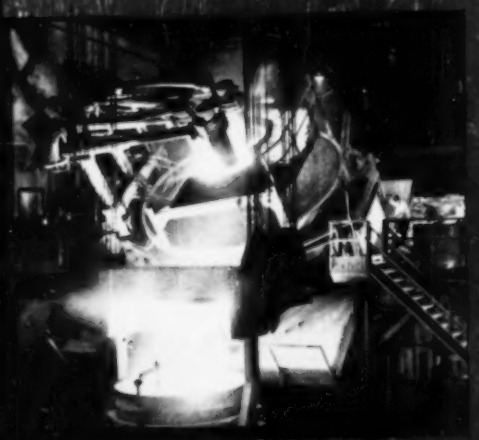
JOURNAL OF

METALS

December 1959





ELECTRIC FURNACE STEEL CONFERENCE ...

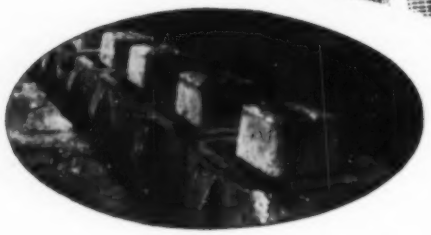
PROGRAM ISSUE

Clean Sinkheads!

C&D's CAUSE NO DEBRIS

With C & D Hot Tops you get:

- **NO DEBRIS** in your stripper.
- **NO REFUSE** along your tracks.
- **NO HAZARDS** from dirty areas.
- **NO CONTAMINATION** in your pits.



THE FERRO ENGINEERING COMPANY
1400 Hanna Bldg. P. O. Box 6508 Cleveland 1, Ohio

Société Francaise d'Etudes et d'Entreprises, Paris, France
Exclusive Licensees for France, Belgium, Luxembourg

REMOVABLE C&D RENEWABLE • RE-USABLE • ADJUSTABLE • FULL-FLOATING

Journal of METALS

VOL. 5, NO. 12 DECEMBER, 1953

Published to provide a continuing, authoritative, and up-to-date record of technological, engineering, and economic progress in all branches of the metals industry by the Metals Branch American Institute of Mining and Metallurgical Engineers, Inc. 29 West 39th Street, New York 18

ALVIN S. COHAN
Manager of Publications
Editor, JOURNAL OF METALS

D. G. GARRETT M. A. MATZKIN
E. M. WEISS G. M. ZILL
Assistant Editors

GRACE PUGSLEY Production Manager
W. J. SEWING Asst. Prod. Mgr.

METALS BRANCH COUNCIL
K. C. McCutcheon Chairman
E. O. Kirkendall Secretary
M. Cohen IMD Chairman
T. J. McLoughlin ISD Chairman
R. R. McNaughton EMD Chairman
W. A. Dean R. D. Parks
T. D. Jones D. S. Eppelsheimer

EDITORIAL ADVISORY COMMITTEE
J. S. Smart, Jr. Chairman
W. A. Dean Evan Just
J. C. Kinnear, Jr. John Marsh
T. D. Jones M. Tenenbaum

TECHNICAL PUBLICATIONS COMMITTEES
Robert Aborn AIME Chairman
Otto Zmeskal ISD Chairman
S. J. Dickinson EMD Chairman
W. R. Hibbard, Jr. IMD Chairman
E. J. Kennedy, Jr. Secretary

JAMES A. STANGARONE
Advertising Manager
FRED STANLEY
Eastern Representative

The AIME Publishes:
Journal of Metals
Mining Engineering
Journal of Petroleum Technology

Electric Furnace Steel Conference Issue

NEWS

Meet the Authors	1586	Journal of Metals Reporter	1609
Employment Service	1588	Electric Furnace Conference Officers	1613
New Products	1593	Electric Furnace Conference Program	1614
Books for Engineers	1596	AIME News	1663
Industrial Notes	1600	IMD Fall Meeting	1666
Trends	1604		
Drift of Things	1606		

TECHNICAL FEATURES

Can the Electric Furnace Compete with the Open Hearth? — C. F. Ramseyer — 1617

McQuaid-Ehn Grain Size Determined by Spectrochemical Analysis — G. E. Ressler — 1622

Reconstruction of CF&I Mill Increases Capacity and Flexibility — W. Brill, R. H. Wright — 1623

Electric Steel Foundries Control Dust Emissions in Los Angeles Area — O. E. Erickson — 1625

Review of Russian Practice Reveals Rail Steel Production Methods — C. A. Zapffe — 1627

Gas Combustion Practice Described for Copper Smelters of the Southwest — Harold Foard — 1629

TRANSACTIONS

Sintering Zinc Concentrates on the Blackwell 12 by 168 Ft Machine — A. E. Lee, Jr. — 1631

Some Observations of Slag-Metal Relations in the Acid Open Hearth Steel Furnace — G. R. Fitterer — 1634

Solid Phase Identification in Partially Reduced Iron Ore — G. Bitsianes, T. L. Joseph — 1641

Exchange of Iron Between Liquid Metal and Iron Silicate Slag — G. Derge, C. E. Birchenall — 1648

After Effects in Polycrystalline Cadmium — C. S. Barrett — 1652

Torsional After-Effect Measurement and Applications to Aluminum — C. S. Barrett, P. M. Aziz, I. Markson — 1655

TECHNICAL NOTES

A Crystallographic Analysis of the Ductile-Brittle Transition in Body-Centered Cubic Single Crystals — A. J. Opinsky — 1650

Surface Structure on Single Crystals Produced from Melt — F. D. Rosi — 1661

Published the first day of each month by the American Institute of Mining and Metallurgical Engineers, Inc., 29 West 39th Street, New York 18, N. Y. Telephone: PEnnsylvania 6-9220. Subscription $8 per year for non-AIME members in United States and North, South and Central America; $10, foreign; $6 for AIME members, or $4 additional in combination with a subscription to "Mining Engineering" or "Journal of Petroleum Technology." Single copies, 75 cents; single copies foreign, $1.00; special issues, $1.50 . . . The AIME is not responsible for any statement made or opinion expressed in its publications . . . Copyright 1953 by the American Institute of Mining and Metallurgical Engineers, Inc. . . . Registered cable address, AIME New York . . . Indexed in Engineering Index, Industrial Arts Index and Chemical Abstracts . . . Reentered as second-class matter Sept. 21, 1949, at the post office at New York, N. Y., under the Act of March 3, 1879. Additional entry established at Manchester, N. H.

Advertisement

ELECTROMET *Data Sheet*

Published by Electro Metallurgical Company, A Division of Union Carbide and Carbon Corporation, 30 East 42nd Street, New York 17, N. Y. In Canada: Electro Metallurgical Company of Canada, Limited, Welland, Ontario.

ALLOYS FOR THE STEEL, IRON, AND NON-FERROUS INDUSTRIES

PRODUCT*	NOMINAL COMPOSITION	USES
BORON ALLOYS		
Ferroboron Min. 10.00% Boron Grade	Aluminum.....max. 0.50% Carbon.....max. 1.50%	Increases hardenability of steel; also, for additions to malleable iron and aluminum alloys.
Min. 17.50% Boron Grade	Aluminum....max. 0.50% Carbon.....max. 0.50%	
Manganese-Boron	Boron.....min. 17.50% Manganese...approx. 75% Carbon.....max. 3% Iron.....max. 5%	Used to cleanse and deoxidize non-ferrous alloys.
Nickel-Boron	Boron.....15 to 18% Carbon.....max. 0.50% Iron.....max. 3.00% Nickel.....Balance	Special boron alloy used principally for deoxidizing nickel and its alloys.
Boron Carbide	Boron.....42 to 48% Carbon .....45 to 52%	Deoxidizer for non-ferrous alloys.
Calcium Boride	Boron.....38 to 42% Calcium.....27 to 32% Carbon.....15 to 20%	Welding rod coating.
CALCIUM ALLOYS		
Calcium-Silicon	Calcium.....30 to 33% Silicon.....60 to 65% Iron.....1.50 to 3%	Deoxidizer for quality ingot steel. Also used in high-tensile gray irons.
Calcium-Manganese-Silicon	Calcium.....16 to 20% Manganese.....14 to 18% Silicon.....53 to 59%	A complex deoxidizer used widely in production of steel castings.
Calcium Metal Regular Grade	Calcium.....98% Balance largely Calcium Chloride	Reducing agent in metallurgical applications, deoxidizer and degasifier for non-ferrous metals.
Distilled Grade	Calcium...approx. 99.50% Balance largely Magnesium	For special applications requiring calcium of very high purity.
CHROMIUM ALLOYS		
"Simplex" Low-Carbon Ferrochrome	Chromium.....63 to 66% Silicon.....5 to 7% Carbon.....max. 0.010% or 0.025%	For producing stainless steel, particularly the low-carbon grades. The silicon in the alloy reduces metal oxides from the slag back into the bath. Rapid solubility of the alloy saves furnace time.
2% Nitrogen-Bearing Grade	Chromium....62 to 65% Silicon.....5 to 7% Nitrogen.....2 to 2.5% Carbon.....max. 0.025%	
5% Nitrogen-Bearing Grade	Chromium....60 to 63% Silicon.....5 to 7% Nitrogen.....5 to 6% Carbon.....max. 0.025%	
Low-Carbon Ferrochrome (Other Grades)	Chromium.....67 to 71% Silicon.....0.30 to 1.00% Carbon (10 Grades) max. 0.03 to max. 2.00%	Production of stainless steels and high-temperature alloys requiring low carbon content.
High-Carbon Ferrochrome		
Max. 4.50, 5.00, or 6.00% Carbon Grade	Chromium.....67 to 70% Silicon..... 1 to 2%	For production of engineering alloy steels and other alloy steels of moderate chromium content.
Max. 7.00% Carbon Grade	Chromium.....66 to 69% Silicon..... 1 to 3%	
Min. 7.00% Carbon Grade	Chromium.....65 to 68% Silicon..... 1 to 3%	
Nitrogen-Bearing Low-Carbon Ferrochrome	Chromium.....67 to 71% Silicon.....0.30 to 1.00% Carbon.....max. 0.10% Nitrogen....0.75 to 2.00%	For additions of nitrogen to improve properties of high-chromium steels.
"SM" Ferrochrome	Chromium.....60 to 65% Silicon ..... 4 to 6% Carbon..... 4 to 6% Manganese..... 4 to 6%	A high-solubility chromium addition for steel or iron in either furnace or ladle.

PRODUCT*	NOMINAL COMPOSITION	USES
CHROMIUM ALLOYS cont.		
Exothermic Ferrochrome	Chromium....60% approx. Carbon.....4.5% max.	These improved exothermic ladle alloys have high solubility, low carbon pickup, and high ignition temperature.
Exothermic Silicon-Chrome	Chromium...46% approx. Silicon..... 23% approx. Carbon.....1.00% max.	
Foundry Ferrochrome High-Carbon Grade	Chromium.....62 to 66% Silicon..... 7 to 10% Carbon..... 5 to 7%	Developed especially for high-solubility ladle additions of chromium to improve composition and properties of cast iron.
Low-Carbon Grade	Chromium.....50 to 54% Silicon.....28 to 32% Carbon.....max. 1.25%	
Chromium Metal Low-Carbon Grades	Chromium.....min. 97% Carbon ..... max. 0.10% and 0.50% Iron.....max. 1%	Production of wide variety of non-ferrous chromium-bearing alloys, including electrical resistance alloys and high-temperature alloys.
High-Carbon Grade	Chromium.....87 to 90% Carbon..... 9 to 11% Iron.....max. 1.25%	
Electrolytic	Chromium.....min. 99%	
"EM" Ferrochrome-Silicon No. 1 Grade	Chromium.....39 to 41% Silicon.....42 to 46% Carbon.....max. 0.05%	Used in production of stainless steel to reduce metal oxides from the slag back into bath.
No. 2 Grade	Chromium.....36 to 39% Silicon.....36 to 39% Aluminum.....7 to 9% Carbon.....max. 0.05%	
"EM" Ferrosilicon-Chrome	Chromium.....50 to 54% Silicon.....28 to 32% Carbon.....max. 1.25%	For adding chromium and silicon to steels containing up to 1 or 2 per cent chromium.
"EM" Chromium Briquets (Hexagonal Shape)	Chromium.....2 lb. Total Weight.....3¼ lb.	For adding chromium to cast iron in the cupola.
COLUMBIUM ALLOYS		
Ferrocolumbium	Columbium.....50 to 60% Silicon.....max. 8% Carbon.....max. 0.40%	Stabilizer in austenitic chromium-nickel stainless steels. Also constituent of high-temperature alloys.
Ferrotantalum-Columbium	Columbium...approx. 40% Tantalum.....approx. 20% Cb+Ta .....min. 60% Silicon.....5 to 7% Carbon.....max. 0.30%	Stabilizer used to supplement ferrocolumbium in chromium-nickel stainless steels. Also used in high-temperature alloys.
MANGANESE ALLOYS		
Standard Ferromanganese Regular Grade	Manganese.....74 to 76% Carbon.....approx. 7% Silicon.....max. 1%	Most common means of adding manganese to steel for both alloying and deoxidizing purposes. Also for counteracting sulphur in steel and cast iron.
Low-Phosphorus Grade	Manganese.....78 to 80% Carbon.....max. 7% Silicon.....max. 2% Phosphorus...max. 0.10%	
Low-Carbon Ferromanganese Low-Phosphorus Grade	Manganese.....min. 90% Carbon.....max. 0.07% Phosphorus...max. 0.06%	Additions of manganese to steels of low-carbon specification, particularly stainless steels of 18 per cent chromium, 8 per cent nickel type.
Regular Grades	Manganese.....85 to 90% Carbon..max.0.07,0.10,0.15 0.30, or 0.50%	
Regular Grade (High-Silicon)	Manganese.....80 to 85% Carbon.....max. 0.75% Silicon..... 5 to 7%	

*All of the alloys and metals listed are produced in the usual lump, crushed, or ground sizes, except where other special forms are indicated.

PRODUCT *	NOMINAL COMPOSITION	USES
MANGANESE ALLOYS cont.		
"Mansiloy" Alloy	Manganese.....60 to 63% Silicon.....28 to 31% Carbon.....max. 0.07% Phosphorus....max. 0.05%	Used in production of stainless steels to reduce metal oxides from the slag back into the bath.
Silicomanganese		
Max. 1.50% Carbon Grade	Manganese.....65 to 68% Silicon.....18 to 20%	A versatile alloy useful as furnace block, deoxidizer, and also for making manganese additions to steel in the ladle or in the furnace.
Max. 2.00% Carbon Grade	Manganese.....65 to 68% Silicon.....15 to 17.50%	
Max. 3.00% Carbon Grade	Manganese.....65 to 68% Silicon.....12 to 14.50%	
Medium-Carbon Ferromanganese	Manganese.....80 to 85% Carbon.....max. 1.25 to 1.50%	For making low- and medium-carbon manganese steel and Hadfield steel.
Low-Iron Ferromanganese	Manganese.....85 to 90% Carbon.....approx. 7.00% Silicon.....max. 3% Iron.....max. 2%	For high manganese additions to certain non-ferrous alloys, particularly aluminum.
Manganese Metal	Manganese...min. 95.50% Carbon.....max. 0.20% Silicon.....max. 1.00% Iron.....max. 2.50%	Used both as deoxidizer and alloy in production of numerous non-ferrous metals and alloys.
"EM" Silicomanganese Briquets (Square Shape)	Manganese.....2 lb. Silicon.....½ lb. Total Weight.....3½ lb.	For adding manganese (with silicon) to cast iron in the cupola.
"EM" Ferromanganese Briquets (Oblong Shape)	Manganese.....2 lb. Total Weight.....3 lb.	For adding manganese (without silicon) to cast iron in the cupola.
SILICON ALLOYS		
50% Ferrosilicon		
Regular Grade	Silicon.....47 to 51%	Deoxidizer for most grades of killed or semi-killed steel. Blocking grade specially sized for maximum efficiency.
Blocking Grade	Silicon.....47 to 51%	
Low-Aluminum Grade	Silicon.....47 to 51% Aluminum.....max. 0.40%	
65% Ferrosilicon		
Regular Grade	Silicon.....65 to 70%	For furnace or ladle addition to steels.
Low-Impurity Grade	Silicon....61.50 to 66.50% Aluminum.....max. 0.50% Total Impurities max. 1.00%	Mainly for production of electrical sheet steel.
75% Ferrosilicon		
Regular Grade	Silicon.....73 to 78%	Deoxidizer and alloy for production of high-silicon spring and electrical sheet steel. Graphitizing inoculant for cast iron.
Low-Aluminum Grade	Silicon.....73 to 78% Aluminum.....max. 0.50%	
85% Ferrosilicon		
Regular Grade	Silicon.....83 to 88%	Enables melter to add higher percentages of silicon without chilling metal in ladle. Graphitizing inoculant for cast iron.
Low-Aluminum Grade	Silicon.....83 to 88% Aluminum.....max. 0.50%	
90% Ferrosilicon		
Regular Grade	Silicon.....92 to 95%	Permits large additions of silicon without harmful chilling effect.
Low-Aluminum Grade	Silicon.....92 to 95% Aluminum.....max. 0.50%	
Silicon Metal		Additions of silicon to non-ferrous metals, particularly aluminum and copper.
Regular Grade	Silicon.....min. 97 or 96% Iron.....max. 1 or 2%	
Purified Grade	Silicon....99.70 to 99.90% Iron.....005 to .015%	For applications in non-ferrous industry requiring silicon of high purity.
Low-Calcium Grade	Silicon.....min. 97% Iron.....max. 1% Calcium.....max. 0.10%	For high-silicon aluminum alloys where calcium is detrimental.
Low-Aluminum Grade	Silicon.....min. 98% Iron.....max. 1% Aluminum.....max. 0.10%	For the production of silicon-copper alloys where aluminum is detrimental.
"SMZ" Alloy	Silicon.....60 to 65% Manganese..... 5 to 7% Zirconium..... 5 to 7%	Particularly strong graphitizing inoculant used in cast iron.
"EM" Silicon Briquets		
Large Size (Cylindrical or Brick-Shape)	Silicon.....2 lb. Total Weight.....5 lb.	For adding silicon to cast iron in the cupola. (Brick-shape briquets are available on pallets.)
Small Size (Cylindrical Shape)	Silicon.....1 lb. Total Weight.....2½ lb.	

"Electromet," "EM," "Mansiloy," "Simplex," "SM," and "SMZ," are trade-marks of Union Carbide and Carbon Corporation.

PRODUCT *	NOMINAL COMPOSITION	USES
SILICON ALLOYS cont.		
Magnesium-Ferrosilicon	Silicon.....43 to 47% Magnesium....7.5 to 9.5%	For ladle addition to cast iron to obtain special properties.
TITANIUM ALLOYS		
Ferrotitanium	Titanium.....27 to 32% Carbon .....max. 0.10%	For stabilized austenitic stainless steels and high-temperature metals.
Silicon-Titanium	Titanium.....40 to 50% Silicon.....45 to 50% Iron.....max. 3%	For additions of titanium to steels or non-ferrous alloys.
Manganese-Nickel-Titanium	Titanium.....43 to 48% Nickel.....approx. 25% Manganese.....max. 8%	Deoxidization of nickel alloys.
TUNGSTEN ALLOYS		
Ferrotungsten	Conforming to A.S.T.M. Spec. A 144-50	For production of tool and die steels; also high-temperature alloys.
Tungsten Metal Powder		
Melting Grade	Tungsten.....min. 98.80% Total Carbon..max. 0.25%	Production of tungsten steels and cast tungsten carbide.
Premium Grade	Tungsten.....min. 99.60% Carbon.....max. 0.20%	
Calcium Tungstate	Tungstic Oxide..68 to 72%	For making tungsten chemicals and other tungsten products.
Calcium Tungstate Nuggets	Tungstic Oxide..68 to 72%	Making tool steels and high-temperature alloys.
Ammonium Paratungstate	Tungstic Oxide..min. 88.7%	Intermediate for tungsten products.
VANADIUM ALLOYS		
Ferrovanadium	Vanadium.....50 to 55% Carbon....max. 0.20, 0.50, or 3.00% Silicon....max. 1.50, 2.00, or 8%; and approx. 10%	Production of tool and engineering steels, high-strength structural steels, non-aging rimming steels, and wear-resistant irons.
Vanadium Oxide Fused	V_2O_5.....86 to 89% Na_2O.....approx. 10% CaO.....approx. 2%	For addition of vanadium to steel and for manufacturing catalysts.
Sodium Polyvanadate (Red Cake)	V_2O_5.....approx. 85% Na_2O.....approx. 9%	For manufacture of vanadium compounds, including vanadium catalysts.
High-Purity Ammonium Metavanadate	V_2O_5.....approx. 99.50% NH_4VO_3.....min. 99%	
ZIRCONIUM ALLOYS		
12 to 15% Zirconium Alloy	Zirconium.....12 to 15% Silicon.....39 to 43% Carbon.....max. 0.20%	This is a powerful deoxidizer. It also increases depth of hardening.
35 to 40% Zirconium Alloy	Zirconium.....35 to 40% Silicon.....47 to 52% Carbon.....max. 0.50%	Deoxidizer for fine grades of alloy steels.
Nickel-Zirconium	Zirconium.....25 to 30% Nickel.....40 to 50%	For deoxidizing and degasifying nickel alloys.
"EM" Zirconium Briquets (Cylindrical Shape, Reddish Color)	Zirconium.....0.55 lb. Silicon.....1.90 lb.	For adding zirconium and silicon to cast iron in the cupola.

IF YOU HAVE A METALS PROBLEM

More than 50 different alloys and metals are produced by ELECTROMET. If you need help in selecting the proper alloys, be sure to consult one of ELECTROMET'S specially trained metallurgists and engineers. Address your inquiries to one of the offices listed below.

Birmingham 3, Ala.....Brown-Marx Building
Chicago 1, Ill.....230 N. Michigan Avenue
Cleveland 14, Ohio.....Union Commerce Building
Detroit 2, Mich.....6-240 General Motors Building
Houston 11, Texas.....6119 Harrisburg Boulevard
Los Angeles 58, Calif.....2770 Leonis Boulevard
New York 17, N. Y.....30 East 42nd Street
Pittsburgh 22, Pa.....Oliver Building
San Francisco 6, Calif.....22 Battery Street
In Canada: Electro Metallurgical Company of Canada Limited, Welland, Ontario

Meet The Authors

C. S. Barrett, (p. 1652) Institute of Metals Lecturer in 1945, last year was visiting professor at the Dept. of Metallurgy, University of Birmingham, England. He spent considerable time abroad in visiting European laboratories and attending technical meetings. Dr. Barrett is a professor in the Institute for the Study of Metals at the University of Chicago. He is a Member of the Chicago Section of the AIME. A graduate of the University of S. Dakota and University of Chicago, Dr. Barrett holds a Ph.D. He was with the Naval Research Laboratory for four years and later was associated with the dept. of metallurgy and metals research laboratory at the Carnegie Institute of Technology for 14 years.

Gerhard Derge (p. 1648) of the Carnegie Institute of Technology is a graduate of Amherst College and Princeton University. He received his Ph.D. in 1934 and has been a member of the staff of the metals research laboratory and professor of metallurgical engineering at Carnegie Tech since that time. An AIME Member, and a resident of Pittsburgh, he has written other papers for AIME in the past. Interests other than his work include fishing and farming.

Thomas L. Joseph, Sr. (p. 1641) has authored or co-authored about a dozen papers on blast furnace and raw materials since 1927. He won the J. E. Johnson, Jr. Award in 1927, the Hunt Award in 1937, and was the Howe Memorial Lecturer for 1946. Mr. Joseph was Chairman of the Raw Materials Committee in 1948. Between 1919 and 1936 he held positions ranging from assistant metallurgist to supervising engineer at the North Central Station of the U. S. Bureau of Mines. Mr. Joseph earned both his B.A. and M.A. degrees at the University of Utah. After an eight year period as head of the dept. of metallurgy of the University of Minnesota, he became professor of metallurgy and assistant dean at the Minnesota Institute of Technology.

F. D. Rossi (p. 1661), senior engineer in the theoretical section, metallurgical laboratory, Sylvania Electric Products, Inc. since 1949, did his undergraduate work and advanced study at Yale. He holds a Ph.D. From 1942 to 1944 he was employed as a metallurgist by International Silver Co. During the last war he served as an engineering officer aboard the U. S. S. Sprig. Dr. Rossi has authored several other papers for the AIME. His leisure time hobbies center around sailing and tennis.

C. Ernest Birchenall (p. 1648) received his Ph.D. from Princeton after completion of undergraduate work at Temple University. He is a junior Member of AIME and an associate professor of chemistry at Princeton. Previous experience includes a stint as a research assistant at Princeton from 1943 to 1946 and a staff position with metals research laboratory at Carnegie Tech. He was also an assistant professor of metallurgical engineering at Carnegie Tech during 1951 and 1952. Dr. Birchenall is interested in tennis, squash, music, and photography. He has authored 15 papers in his particular fields of technical interest.

C. F. Ramseyer, (p. 1617) of Ramseyer & Miller, Inc., went to work at the Illinois Steel Corp. South works in Chicago after graduation from Harvard. He worked in various operating departments, particularly the blast furnace and later in processing and metallurgical research. During the '30's he was a research engineer with a large power company working on development of markets for boiler ash. He did original work on development of use of fly ash from pulverized fuel boilers in concrete. He went to H. A. Brassert & Co. during the '40's as assistant to the president and as a metallurgical engineer. Mr. Ramseyer started the firm of Ramseyer & Miller with J. R. Miller in 1950.

P. M. Aziz (p. 1655) is a member of the Faraday Society and the Chemical Institute of Canada. After finishing graduate work at the University of Toronto, he was employed by Aluminium Laboratories, Ltd. as a research chemist. He has held that position to the present, with time out for work as a research associate for the study of metals at the University of Chicago. Among his free time hobbies are high fidelity music reproduction and sailing.

P. M. AZIZ

H. FOARD

Harold Foard (p. 1629) is superintendent for the International Smelting & Refining Co. at Miami, Ariz. Mr. Foard gained experience working in Mexico and was also associated with Cerro de Pasco Copper Corp. In 1933 he joined the International Agricultural Corp. as a chemist. He has been associated with International Smelting since 1937, joining as a test engineer. Machine and metal work occupy him in his free time and he is also an amateur gunsmith.

Albert E. Lee, Jr. (p. 1631), born at Beverly, N. J., is a graduate of Lehigh University. Mr. Lee was a trainee for acid plant supervisor with the Atlas Powder Co. In 1941 he was called to duty as ordnance reserve officer working on inspection and production control of powder and explosives for the Philadelphia Ordnance district. He joined Blackwell Zinc Co., in 1946 and is presently superintendent. Mr. Lee is an AIME Member.

Superior
BLAST FURNACE
COPPER CASTINGS
Hot Blast Valves and Valve Seats
Blast Furnace Tuyeres. Licensed Manufacturers of all Leading Designs
Casting Plates of all kinds including Heavy Nose Super Cooled Bosh Plates.
SMEETH-HARWOOD COMPANY
8524 Vincennes Ave., Chicago 20, Ill.
In Canada—The William Kennedy & Sons, Ltd., Owen Sound, Ontario
Blast Furnace Copper Castings—also Brass and Bronze Mill Castings

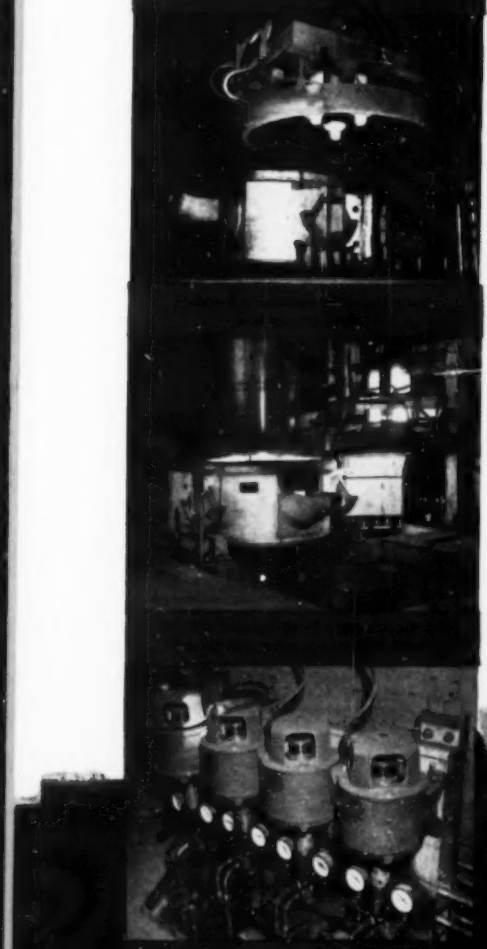
WHITING

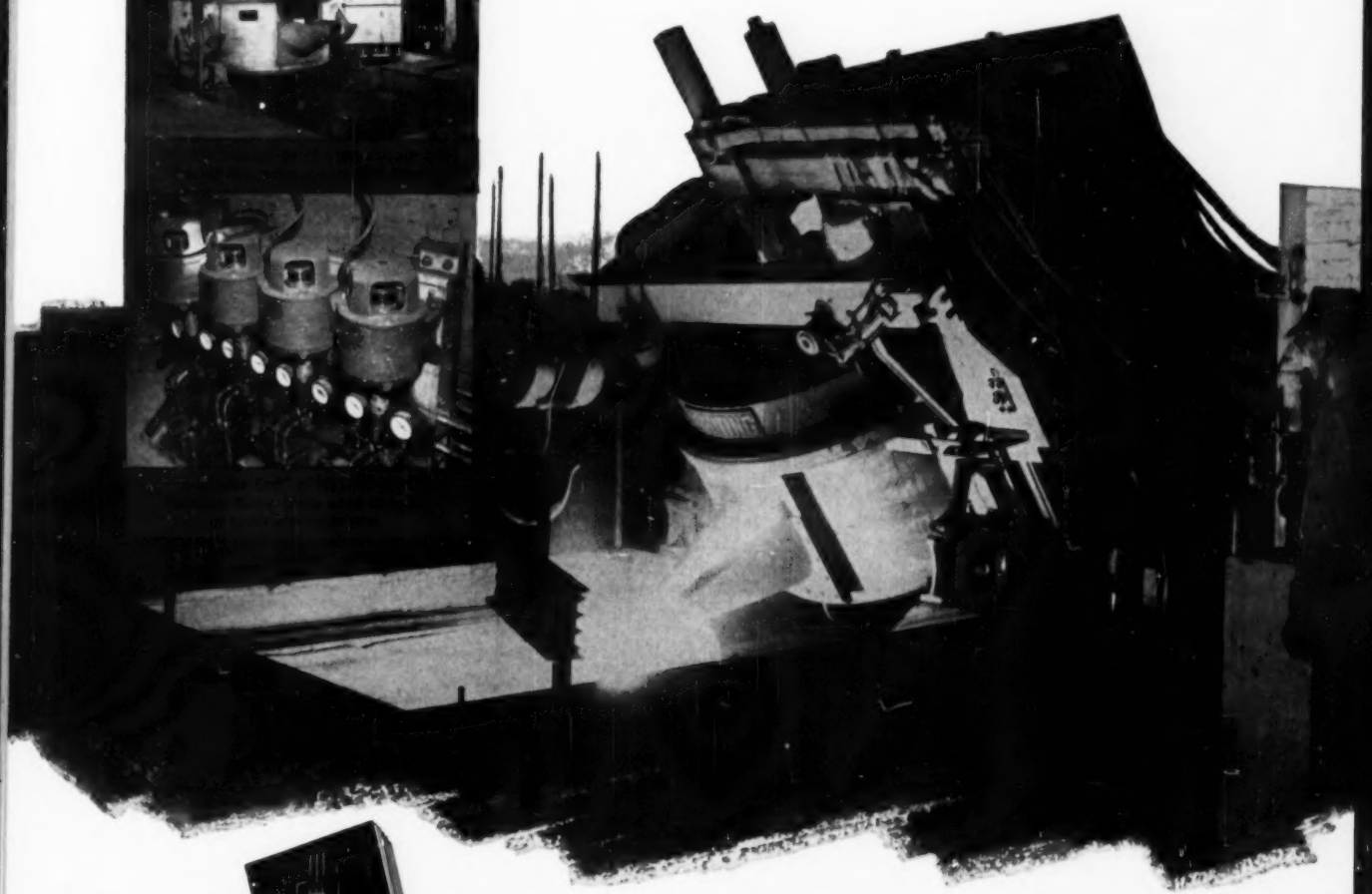
Hydro-Arc

HERE'S THE "Pace-Setter" IN ELECTRIC MELTING!

You ask, "What electric furnace offers the most advantages?" The answer is WHITING HYDRO-ARC because of its important, advanced engineering principles! To name a few:

- **The Hydro-Arc Automatic Electric Clamp,** pioneered by Whiting, saves up to 90% of furnace down-time for slipping electrodes. It also means an 8% increase in operating time and production . . . and in addition, the elimination of the hazardous electrode slipping operation.
- **The Unique Hydro-Arc Top Charge,** a load factor improvement, reduces furnace down-time for recharging to only a few minutes. Because of its sound, basic simplicity, limit switches are eliminated and maintenance is held to a minimum.
- **The Hydro-Arc Air-Counterbalanced Hydraulic Electrode Positioning Equipment** assures less electrical energy and electrode consumption as well as improved metallurgical control and longer refractory life.





Write today . . . for 40 page bulletin FY-168. It completely describes Whiting Hydro-Arc Electric Arc Furnaces!

WHITING CORPORATION

15602 Lathrop Avenue, Harvey, Illinois

Metallurgical Engineer

Applications are invited from graduate Metallurgical Engineers, preferably in the age range 40 to 45, who have had not less than ten years broad and responsible experience in the field of nonferrous extraction metallurgy, for the position of Assistant Metallurgist to the undermentioned Corporation. The position entails duties in connection with the important group of Northern Rhodesian mining companies producing copper, cobalt, lead, zinc and other base metals, to which the Corporation acts as Consulting Engineers.

The salary to be offered will be commensurate with the successful candidate's qualifications and experience. Membership of the Corporation's Pension Fund will be a condition of employment.

Applicants must be prepared to take up residence in Kitwe, Northern Rhodesia. The cost of transportation of the successful candidate, his wife and children up to 18 years of age and reasonable personal effects will be borne by the Corporation. A modern three-bedroomed brick house, with essential furniture, will be made available at a rental which will not exceed $28.00 per month.

Excellent medical facilities are provided and recreational amenities are outstanding.

Initially the engagement will be for a period of three years, after which service may be extended indefinitely, but will be subject to six months notice of termination by either party. Repatriation privileges on the same scale as above will be granted at the end of three years service. Leave is generous and amounts at present to 60 days per annum which can be accumulated up to a maximum of 180 days.

Applications stating age, marital status, educational and professional qualifications and giving details of past experience and positions held should be addressed to:

Personnel Officer,

Anglo American Corporation of South Africa, Limited,

P.O. Box 4587,
JOHANNESBURG.

—Personnel Service—

THE following employment items are made available to AIME members on a nonprofit basis by the Engineering Societies Personnel Service, Inc., operating in cooperation with the Four Founder Societies. Local offices of the Personnel Service are at 8 W. 40th St., **New York 18;** 100 Farnsworth Ave., **Detroit;** 57 Post St., **San Francisco;** 84 E. Randolph St., **Chicago 1.** Applicants should address all mail to the proper key numbers in care of the New York office and include 6c in stamps for forwarding and returning application. The applicant agrees, if placed in a position by means of the Service, to pay the placement fee listed by the Service. AIME members may secure a weekly bulletin of positions available for $3.50 a quarter, $12 a year.

MEN AVAILABLE

Metallurgical Engineer, 38, married. Eleven years' experience nonferrous metallurgy lead, zinc, copper, bismuth, silver, gold. Locate U. S. or Canada. Available immediately. M-114.

Mining Metallurgical Engineer, 30, B.E.M., also law degree, desires executive position in U. S. or Western Europe. Experienced research, materials evaluation, coal cleaning, open pit operations, corrosion, and administration. Excellent knowledge of German, Danish. Available immediately. M-115.

Metallurgical Engineer, B.E. degree with honors and one year of graduate work in industrial engineering. Age 25. One year's experience on research on wrought magnesium alloys which consists primarily of laboratory rolling and extrusion and some work on production rolling problems. Prefer position in production, metallurgical or industrial engineering. M-116.

TECHNICAL MEN — A progressive specialty steel company located in the East is organizing a Research and Development Laboratory and needs several competent Junior and Senior technical men capable of filling responsible positions.

BOX K-28 JOURNAL OF METALS

METALLURGISTS

Would you like to work in A CHALLENGING NEW FIELD—the DEVELOPMENT of MATERIALS and PROCESSES for COMPONENTS of NUCLEAR REACTORS? We need top-flight men at the INTERMEDIATE and SENIOR LEVEL to participate in one of the most momentous programs of this century.

MODERN LABORATORIES, SUPERBLY EQUIPPED, located in suburban Pittsburgh eleven miles southeast of the New Golden Triangle. UNIQUE OPPORTUNITY FOR GRADUATE STUDY WHILE WORKING. Housing of all types readily available in attractive communities nearby.

Write today to Supervisor, Industrial Relations, P. O. Box 1468, Pittsburgh 30, Pa.

WESTINGHOUSE
ATOMIC POWER DIVISION

POSITIONS OPEN

Sales Engineer, 30 to 40, with mechanical or metallurgical training, machinery and sales experience covering steel tubing for importer. Salary, $6000 to $8000 a year plus bonus. Location, New York. Y9313.

Research Metallurgist interested in teaching, to head up a department, half time teaching and half time on sponsored industrial research. Salary, $10,000 a year. Location, Midwest. Y9282.

Metallurgist to be responsible for laboratory test, research, laboratory production-liaison work, interpretation of all laboratory data and the maintenance of permanent and accurate records. Location, South. Y9274.

Metallurgist, 25 to 40, for research and development laboratory. Must be able to make tests and write a good report. Salary, $6000 to $7000 a year. Location, New York, N. Y. Y9253.

Metallurgist Assistant, ore dressing, to do mineral dressing research on metallic and nonmetallic ores. Must be a technical graduate, with some training in ore dressing research methods, preferably with several years laboratory or operating experience, but graduate work or other special qualifications will be considered in lieu of experience. Salary will be augmented by 25 pct cost of living allowance. Transportation for employee and family paid. Location, Alaska. F9234.

Assistant Metallurgist, 40 to 45, metallurgical engineer, with at least ten years broad and responsible experience in nonferrous extraction metallurgy, for consulting firm working with copper, cobalt, lead, zinc and other base metals mining companies. Salary open. Transportation paid for employee and family. Give age, education and experience in making application. Location, South Africa. F9206.

Metallurgical Engineeer, graduate, for experimental work in process metallurgy; two to five years experience with open hearth or electric furnace operation; practical knowledge of melting, refining, pit practice; mechanical aptitude and resourcefulness especially desirable; for permanent assignment in sales development laboratory, New Jersey. Describe academic, military, industrial experience, salary desired. Y9084(b).

Pyrophyllite, titania or glaze frits...

Ceramics industry gets fast, accurate quantitative analysis with GE fluorescent x-ray spectrometer

As in so many other fields, fluorescent x-ray spectroscopy is finding wide application in ceramics. To cite a few examples...

In research — to determine the amount of cobalt and nickel deposited during the firing of enamel ground coats.

In raw material analysis — to speed the determination of niobium in titanium oxide ... of iron in pyrophyllite.

In product control — to permit easy comparison of the amounts of lead in glaze frits.

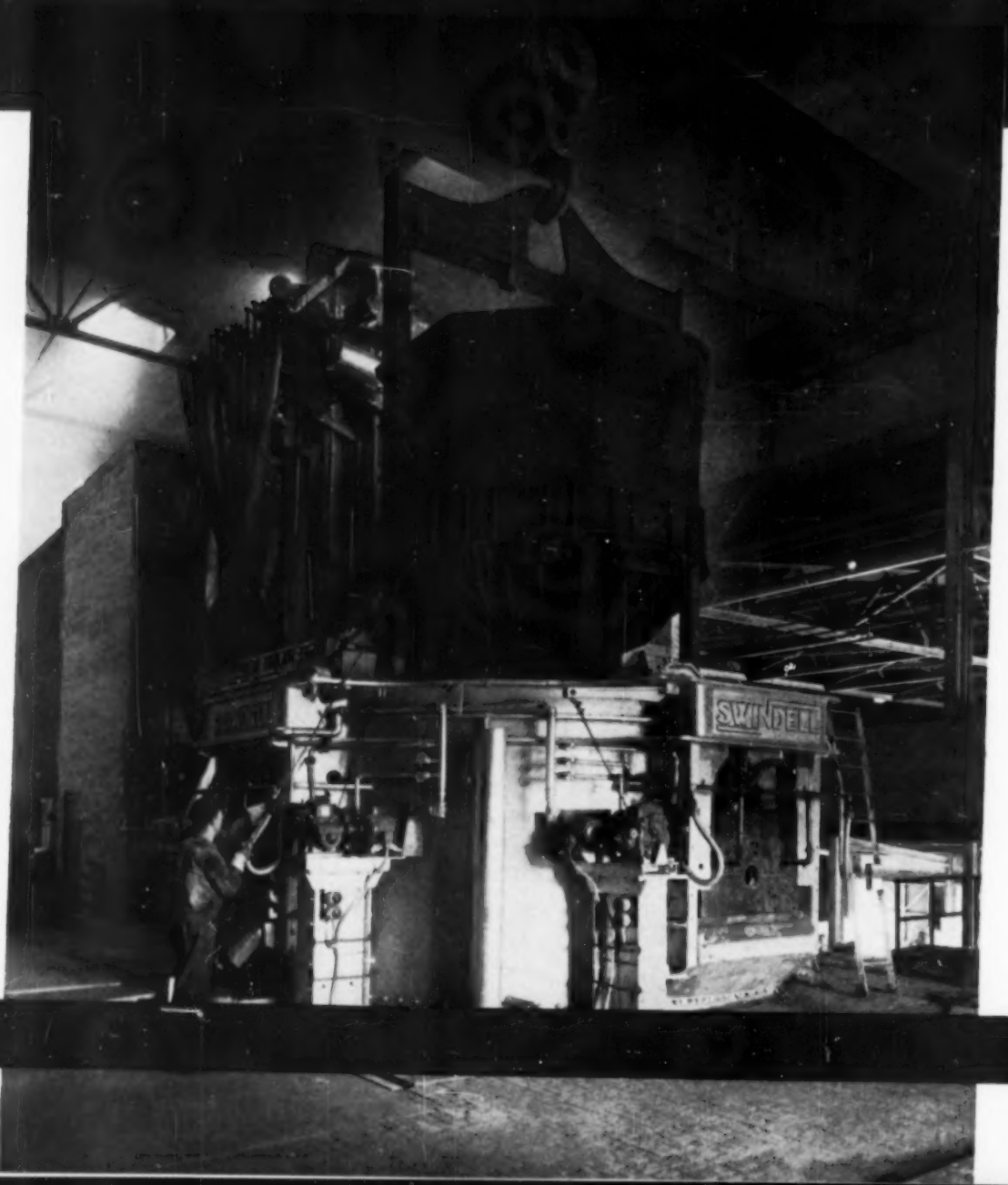
And GE XRD-3S spectrometers are proving their value in other industries — chemical, petroleum, mineral, metallurgical. Everywhere they maintain high accuracy over a wide range of concentrations. They're fast — only one to five minutes per element on any atomic number above 22.

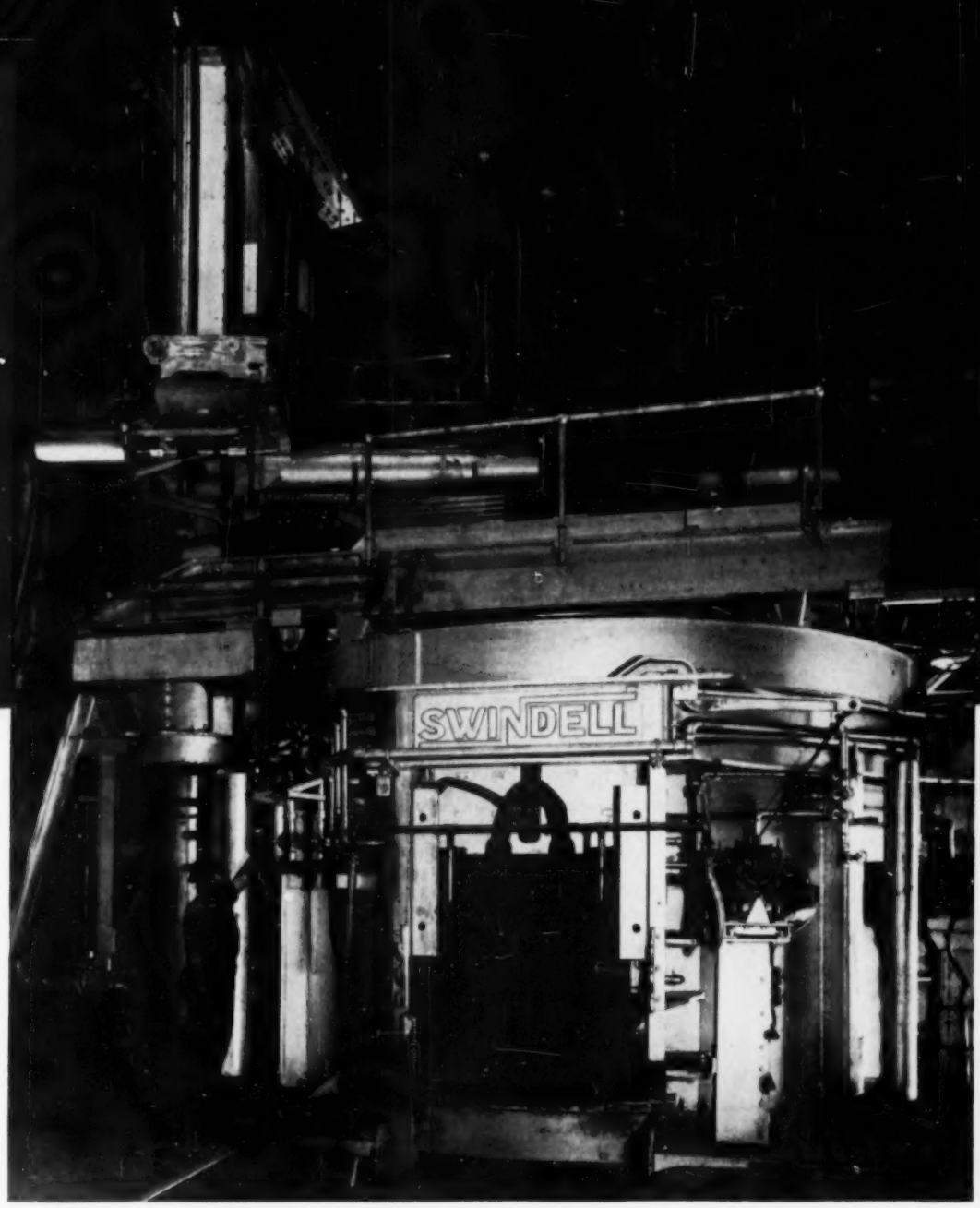
If you need fast, accurate analysis of your materials, get all the facts about fluorescent x-ray spectroscopy. A recent article by R. F. Patrick of Pemco Corporation tells how they make profitable use of x-ray diffraction in the ceramic field. For this or other applications, write X-Ray Department, General Electric Company, Milwaukee 1, Wisconsin, Rm. AY-12.

You can put your confidence in —

GENERAL ELECTRIC

SWINDELL





Modern Features

- Flush door mechanism
- Power holders
- Water cooled ring on shell
- Large OD roof ring
- Mechanical trip charging bucket
- Elevator type safety stop masts
- Higher sidewalls
- No exposed winch gearing
- Fully protected tilt mechanism with positive stop

SWINDELL-DRESSLER CORPORATION

P. O. BOX 1888 • PITTSBURGH 30, PA.

A Report from Vanadium Corporation

How Vanadium Corporation's long-range expansion program is helping industry.

CHROMIUM ALLOYS

Vanadium Corporation's new plant at Graham, West Virginia, has been especially equipped to produce—by a unique new process—a remarkably clean, dense new *low carbon ferrochromium*. This new alloy combines a normal silicon content with a high chromium-to-carbon ratio which enables the steelmaker to produce stainless steels of extremely low carbon content without resorting to modification of furnace and melting practices.

The new Graham plant also produces various alloys of *ferrochrome-silicon*. Additional modern facilities at Niagara Falls are producing increased quantities of *high-carbon ferrochromium* by Vanadium's exclusive process. There is an ever growing demand for these clean, high-density Vancoram Alloys—particularly in the many applications where quality and economy are primary considerations.

GRAINAL ALLOYS

These are the multiple-element alloys developed by Vanadium Corporation that are now being used to produce annually over *a million tons of boron steels*. Replacing critical and more costly elements with respect to hardenability and other properties, Grainal Alloys have proved invaluable not only in times of heavy defense production but also in providing low-cost, high-quality alloy steels for our peacetime economy.

New use for Grainal Alloys: alleviating the problem of hot shortness in *stainless steels*. Field reports indicate that small additions of Grainal improve the hot working characteristics of stainless, thus cutting conditioning costs and increasing output.

Anticipating the future demand for Grainal Alloys, Vanadium Corporation has included at its new plant at Cambridge, Ohio, additional facilities for their production.

VANADIUM ALLOYS

With government restrictions on the use of vanadium now lifted, steelmakers can once again take full advantage of Vancoram *ferrovanadium*. Small additions of this versatile, economical alloy often do the work of large amounts of other, more expensive alloys—*a little goes a long way*.

Vanadium Corporation has played an important role in helping to make vanadium again available in large commercial quantities.

For example . . .

New VCA mines in Colorado have substantially increased the production of *vanadium ore* in conjunction with western uranium operations.

Complete new facilities at the Cambridge, Ohio, plant will soon be in full operation to further insure a plentiful supply of highest quality ferrovanadium for every application—from watch springs to giant forgings.

More news about Vancoram Ferrovanadium: Available for many years both in bags and drums, ferrovanadium can now be furnished palletized for greater shipping economy and ease of handling.

SILICON METAL AND ALLOYS

Among the promising new nonmetallic materials developed during World War II are the Silicone plastics. Their outstanding properties include resistance to both high and low temperatures—thanks to *silicon metal* used in their manufacture.

Vanadium Corporation's new Graham plant provides the plastics industry with a dependable new source of silicon metal of highest quality.

The new Graham plant is also furnishing a complete range of silicon metal and *ferrosilicon* to the aluminum, iron, steel, magnesium and other industries.

RESEARCH

Now nearing completion at the Cambridge plant is the new enlarged Research Center. This new center contains extensive, modern facilities for the further development of all Vancoram products—which also include, *titanium alloys, master aluminum alloys*, and a complete range of *foundry alloys* for every application.

VANADIUM CORPORATION OF AMERICA

420 Lexington Avenue, New York 17, N. Y.

Producers of alloys VANCORAM metals and chemicals

PITTSBURGH • CHICAGO • DETROIT • CLEVELAND

PLANTS: Niagara Falls, N. Y., Graham, W. Va. Cambridge, Ohio

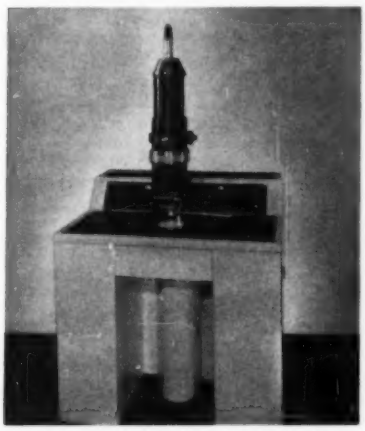
New Products

New Products | New Literature | New Services

For Further Information or Literature on any Product, Fill in the Coupon and Send to JOURNAL OF METALS

Students are Requested to Apply Directly to Manufacturers for Bulletins and Information

1—ELECTRON MICROSCOPE: *North American Philips Co., Inc.* announced a new Philips Electron Microscope, EM-75, with half the power and at half the cost of the EM-100. Magnification is continuously adjustable between 1500 and 15,000 diam, and variable between 10 and 75 kv. Under average conditions resolving power is better than 100 Angstroms. The new unit has a



magnetic stabilizer for high voltage and lens currents. The electron gun is self-biased, is equipped with an emission meter, and the V-shaped filaments are easily replaced.

2—MOLDING PRESS: *F. J. Stokes Machine Co.* has redesigned its toggle type semi-automatic compression molding press. Model 731 is suited to molding delicate parts such as resistors, capacitators and similar plastic molded forms. As are earlier Stokes toggle presses, the new design is equipped with the Stokes patented bar controller which reportedly gives positive mechanical control over every phase of the molding cycle.

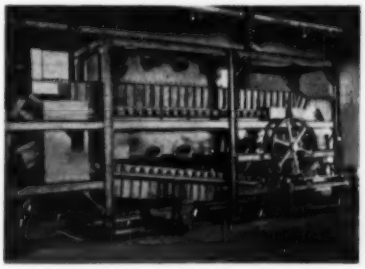
3—TEMPERATURE CONTROLLER: A new electronic temperature controller with increased range—from −100° to +600°F—has been introduced by *Minneapolis-Honeywell Regulator Co.* for industrial applications requiring precise and consistent temperature control but not the functions of indicating or recording. Called the New 077, the controller uses the resistance thermometer principle and is claimed to be unusually flexible in the type of control provided by a single-point model. The controller is also available in cascade control models utilizing two bulbs.

4—BERYLLIUM FLAKE: *Beryllium Corp.* offers a metallic beryllium flake with a minimum purity of 99.5 pct. An exclusive feature claimed for it is its high ductibility, making it particularly suitable for fabricating applications such as hot pressing.

5—FLUORIMETER: Need for air or water cooling, or optical meters has been eliminated from a new G-M Fluorimeter in production by *Jarrell-Ash Co.* The instrument consists of three basic units: an ultraviolet light chamber and simple slide; a detecting and measuring unit; and a power supply. All units except the power supply are mounted in an attractive gray metal base forming a compact and portable instrument. With the cooling system eliminated, the sample slide, light source, and detecting unit can be mounted in close proximity, making optical systems unnecessary, according to the manufacturer.

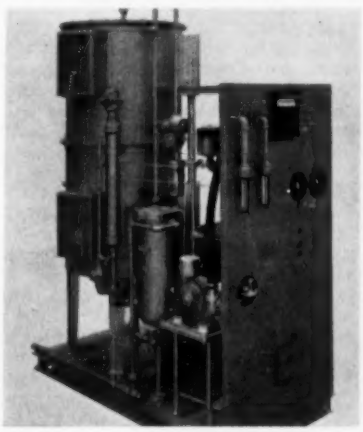
6—SHELL MOLDING MACHINE: New model HO-4 Shalco Shell Molding Machine, introduced by *Shallway Corp.*, is reported to incorporate new features increasing output and mold uniformity. The machine features dual dump boxes and choice of gas or electric curing oven. The unit is available with automatic timers for both inversion and curing cycles and is said to produce up to two shells per minute. Standard equipment includes automatic dump box clamps, counter balanced pattern frame and dump boxes, sealed ball bearings, positive air-actuated shell ejection, thermostatically controlled pattern temperature, and heat resistant permanently bonded silicone dump box seals.

7—SINTERING MACHINES: The new Dwight-Lloyd pilot line of sintering machines introduced by *Sintering Machinery Corp.* includes all features of the larger production units and are capable of operation both by down draft or up draft, or in combination. Gases may be re-



circulated either by pressure or suction for full heat recuperation or gas enrichment. Admission of free air can be controlled to meet process requirements. Top ignition, bottom ignition, layered charging and other methods being researched have been provided for. These all-purpose research-pilot machines are produced in sizes from the 12 in.x4-ft hearth area research machine to 36x30-ft research-pilot machine.

8—GAS GENERATOR: An endothermic gas generator is now available after a two-year testing period in production plants. Developed by *Hevi Duty Electric Co.*, it is claimed that the generator will produce con-



trolled atmosphere of consistent chemical analysis for heat treating operations such as: bright hardening of high carbon steels without oxidation or decarburization; bright hardening of molybdenum, tungsten, and cobalt high speed steel; annealing and normalizing; bright copper brazing, carburizing, and carbonitriding; and sintering and powder metallurgy processes that require a reducing atmosphere. Air filter, air gas mixing machine, gas cracking chamber, gas cooler, control panel, and power transformer are all mounted on a structural steel base.

Free Literature

20—CALCULATOR: *Republic Steel Corp.* has prepared a handy calculator for annealing alloy steels to produce lamellar and spheroidal structures. Prepared by Republic metallurgists, this handy slide cal-

culator provides data on standard AISI analyses ranging from 1035 to 9850, for conventional and isothermal anneal. One side presents spheroidal structure information and the other lamellar structure data.

21—BEAM FAILURE: How to avoid beam failure in torsion and in compression is explained in a *Reynolds Metals* technical advisor. The publication discusses the most effective design for aluminum beams subject to bending stresses. This is the second section of a two-part article on structural aluminum design.

22—INDICATORS: Information on how manually-operated portable and panel indicators are used to measure temperature, electrolytic conductivity, or pH is contained in a 24-pp. catalog published by *Leeds & Northrup Co.* Instruments in the catalog are arranged according to application. Circuit diagrams show how they operate. Typical installations are shown by photographs.

23—MATERIALS HANDLING: *Heppenstall Co.'s* new brochure illustrates automatic, motorized and spacer tongs made by the firm. Particular applications for the most efficient use are described. Tongs are made for a variety of shapes, sizes, and weights ranging from 160,000-lb ingots down to wooden and paper boxes.

24—FOUNDRY OPERATION: *Fischer & Associates* Foundry Engineering Div., has published a two page questionnaire designed to provide an efficiency analysis of all foundry operations and point out weak spots in production equipment and methods. The check list can be used by ferrous and nonferrous foundries and takes only a few minutes to complete.

25—WELDING: Welding of nickel alloy steels is the subject of a bulletin issued by *International Nickel Co., Inc.* It is a study of various welding techniques, including some of the new inert gas processes, electrodes, preheat treatments, and post heat treatments. The 44-pp. bulletin gives typical results that can be expected for low alloy high strength steels, low carbon and medium carbon engineering alloy steels, and special steels.

26—CLAD STEEL: Advanced techniques for fabricating clad steels are outlined on a wall-mount chart developed by *Lukens Steel Co.* The chart gives all basic information for arc-welding and flame cutting clad steel plates.

27—REFRACTORY SELECTION: Refractories Div. of *Norton Co.* has issued a 32-pp. booklet designed to help in the proper selection of refractories for critical areas in boilers for heat and power. It contains detailed information on characteristics and manufacture of Crystolon refractories and suggestions for the use of Crystolon refractories for many different types of boilers.

28—THERMISTORS: Four technical data sheets issued by *Carboloy Dept. of General Electric Co.* offers the latest information on methods of using thermistors, heat sensitive electrical resistors with negative temperature co-efficient. A description of a new physical demonstration of permanent magnet properties is also available.

29—INSULATIONS: An 8-pp. catalog issued by *Johns-Manville* gives concise data on properties of the various products produced by J-M and includes photographs showing typical installations. Products covered are: Industrial insulations for temperatures from −400°F to +3000°F; refractories and insulating brick for furnaces, ovens, and kilns operating to +3000°F; Transite pipe for overhead and underground water lines and for process lines handling corrosive liquids and gases; Transite industrial vent pipe for venting gases, ducts, fumes, and vapors; packings and gaskets including acid and caustic-resisting types; raschig rings for tower packings; and J-M Chemstone and Transite sheets for various types of fabricating equipment.

30—TITANIUM: An illustrated booklet describes the operations of the *Mallory-Sharon Titanium Corp.* It describes advantages, production methods, some of the uses of titanium, and how the metal can be employed by fabricators.

31—GEARS: A 36-pp. booklet published by *Meehanite Metal Corp.* describes and illustrates many Meehanite gear applications and goes into detail on gear casting design. Also provided are properties of both types of Meehanite metal used in gearing and other gear materials.

32—GAMMA RADIOGRAPHY: This publication by *Technical Operations, Inc.* discusses two pieces of equipment developed by the firm. The directional exposure shield allows intensive cobalt 60 gamma radiation to be used as x-radiation is used—in a beam and directed at the specimen—without hazard to the operator. The panoramic exposure shield allows use of strong cobalt 60 sources in panoramic exposures and in internal exposures without danger.

33—BALL BEARINGS: A new 20-pp. bearing catalog published by *Miniature Precision Bearings, Inc.*, offers comprehensive design and application data on miniature ball bearings. Information on ball bearings in sizes ranging from 0.100 to 0.375 in. OD is presented and supported by drawings, graphs, tables, and photographs.

34—SILICON CARBIDE: *Carborundum Co.* has issued a 52-pp. brochure describing properties of silicon carbide in manufacture of superrefractories and refractory cements, electrical heating elements, resistors, a deoxidizer in metallurgy of iron and steel, catalyst carriers, and porous media. Manufacturing techniques are outlined. The brochure contains an extensive bibliography.

35—BERYLLIUM CU: Ways in which beryllium copper can help engineers solve design problems are illustrated by actual uses in booklet offered by the *Beryllium Corp.* Ease of fabrication, high strength, good electrical and thermal conductivity, excellent resistance to wear and corrosion, and unusual castability are qualities stressed.

Journal of Metals
29 West 39th St.
New York 18, N. Y.

December

Please send me { More Information ☐ / Free Literature ☐ / Price Data ☐ } on items indicated.

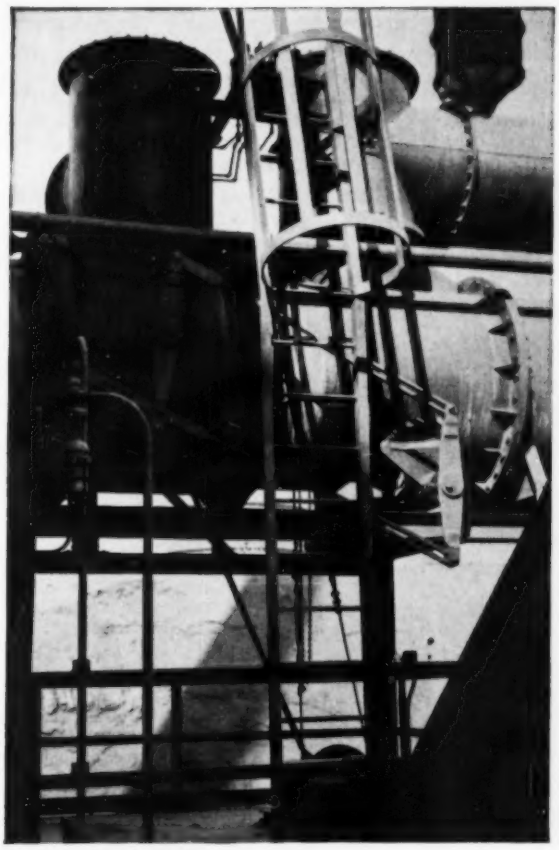
1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50

Name..... Title.....

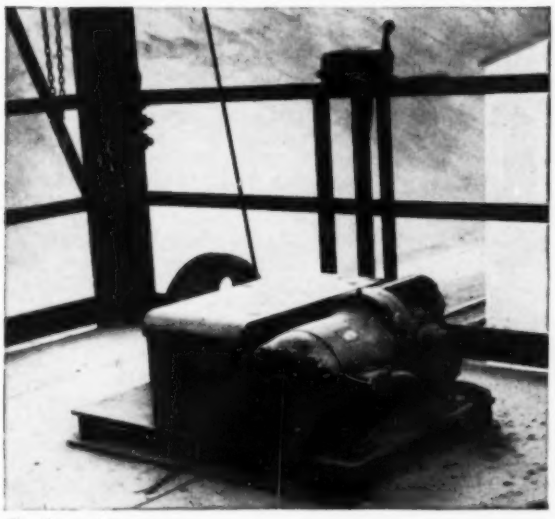
Company.....

Street.....

City and Zone..... State.....



The Complete Assembly



The Operator

The Venerable SNORT VALVE may now be MOTOR OPERATED

- The operator is adaptable to a variety of valve designs.
- Existing valves may be electrified.
- Mechanical operation of the valve is preserved intact.
- Electrical operation is the normal mode. In the event of power failure, reversion to manual operation is automatic.
- A small master switch supplants the hand wheel.
- Multiple stations for electrical operation are provided.
- Quicker response, easier control.

SUCCESSFUL OPERATION DEMONSTRATED

KOPPERS

METALLURGICAL PLANT DESIGN AND CONSTRUCTION

KOPPERS COMPANY, INC.

Freyn Engineering Department

KOPPERS BUILDING • PITTSBURGH 19

Books for Engineers

METAL SINGLE CRYSTALS

Now available:

High purity iron

Aluminum	Bismuth
Brass	Bronze
Cadmium	Copper
Gold	Lead
Magnesium	Nickel
Silver	Tin
Zinc	Permalloy

Special Alloys

CUSTOM MELTING OF SPECIAL ALLOYS

This service is now available for vacuum and inert atmosphere melting of experimental heats on request.

We will be pleased to submit prices and specifications for any unusual requirements you may have in these fields.

HORIZONS INCORPORATED
2891-2905 E. 79th St.
Cleveland 4, Ohio
BR 1-1601

PROFESSIONAL SERVICES
Limited to AIME members, or to companies that have at least one AIME member on their staffs. Rates $40 per year per inch.

SCIENTISTS
CONSULTANTS
METALLURGISTS
Small Jobs Welcomed
SAM TOUR & CO., INC.
Laboratories and offices
44 Trinity Place, New York 6, N. Y.

Testing—Certifying
American Standards
Testing Bureau, Inc.

MAX STERN
Consulting Engineer
Expert for Scrap Recovery and Shipwrecking — Modernization of Plants and Yards for Ferrous and Nonferrous Metal Scrap
149 Broadway New York 6, N. Y.

ORDER YOUR BOOKS THROUGH AIME—Address Irene K. Sharp, Book Department. Ten per cent discount given whenever possible. Order Government publications direct from the agency concerned.

Metallurgical Dictionary, by J. G. Henderson. *Reinhold Publishing Corp.* $8.50, 396 pp., 1953.—The book is arranged specifically for the needs of all metal industries and contains more than 5000 informative definitions and descriptions covering all the most essential terms in both production and physical metallurgy. It is semi-encyclopedic in nature; and has been selectively limited in scope so as not to deluge the reader with obsolete or remote material.

Protective Atmospheres, by A. G Hotchkiss and H. M. Webber. *John Wiley & Sons, Inc.* $7.00, 341 pp., 1953.—The book is aimed at persons who supervise manufacturing operations, plant engineers, and metallurgists. It seeks to supply usable information on the various phases of protective atmospheres. Data showing compositions and costs of typical protective atmosphere gases, common industrial processes for which the atmospheres are used, materials processed, requirements met, and recommended atmospheric gases for the applications are tabulated for ready reference in chapter one. The book is not intended, however, to be a scientific treatise on theory or on equipment design. Emphasis has been placed on practical aspects that can serve as an operating manual.

Foams, Theory and Industrial Applications, by J. J. Bikerman in collaboration with R. B. Booth, J. M. Perri, and C. C. Currie. *Reinhold Publishing Co.* $10.00, 450 pp., 1953.—The book offers a critical review of world literature on foam and presents what has been termed a thoroughly up-to-date treatment of its physical chemistry and industrial uses. The first section of the book, comprising about three fourths of the material, is devoted to the chemical and physical properties of foams. Remaining chapters describe important applications of foams.

Applied Elasticity by Chi-Teh Wang. *McGraw Hill Book Co., Inc.* $8.00, 357 pp., 1953.—The book is the outgrowth of a course presented by the author at New York University for the past eight years. The author had two purposes in mind in preparing these lecture notes: First, to provide the student with the necessary fundamental knowledge of the theory so that he will be able to formulate any problem occurring in the classical theory of elasticity; second, to acquaint the student with the most useful analytical and numerical methods so that after the problem is formulated, it can be solved by one of these methods.

Electrostatique et Magnetostatique, by E. Durand. *Masson et Cie.* About $18.10, 774 pp., 1953.—Opening chapters of this comprehensive treatise are devoted to electrostatics: Fundamental equations of distribution of charges, conductors, dielectrics, forces within the electrostatic field, and various special topics such as electrostriction and piezoelectricity. Succeeding chapters deal similarly with magnetostatics, and include discussions on diamagnetism, paramagnetism, and ferromagnetism. The extensive mathematical treatment covers analytical solutions for two and three variables, with a large number of numerical solutions.

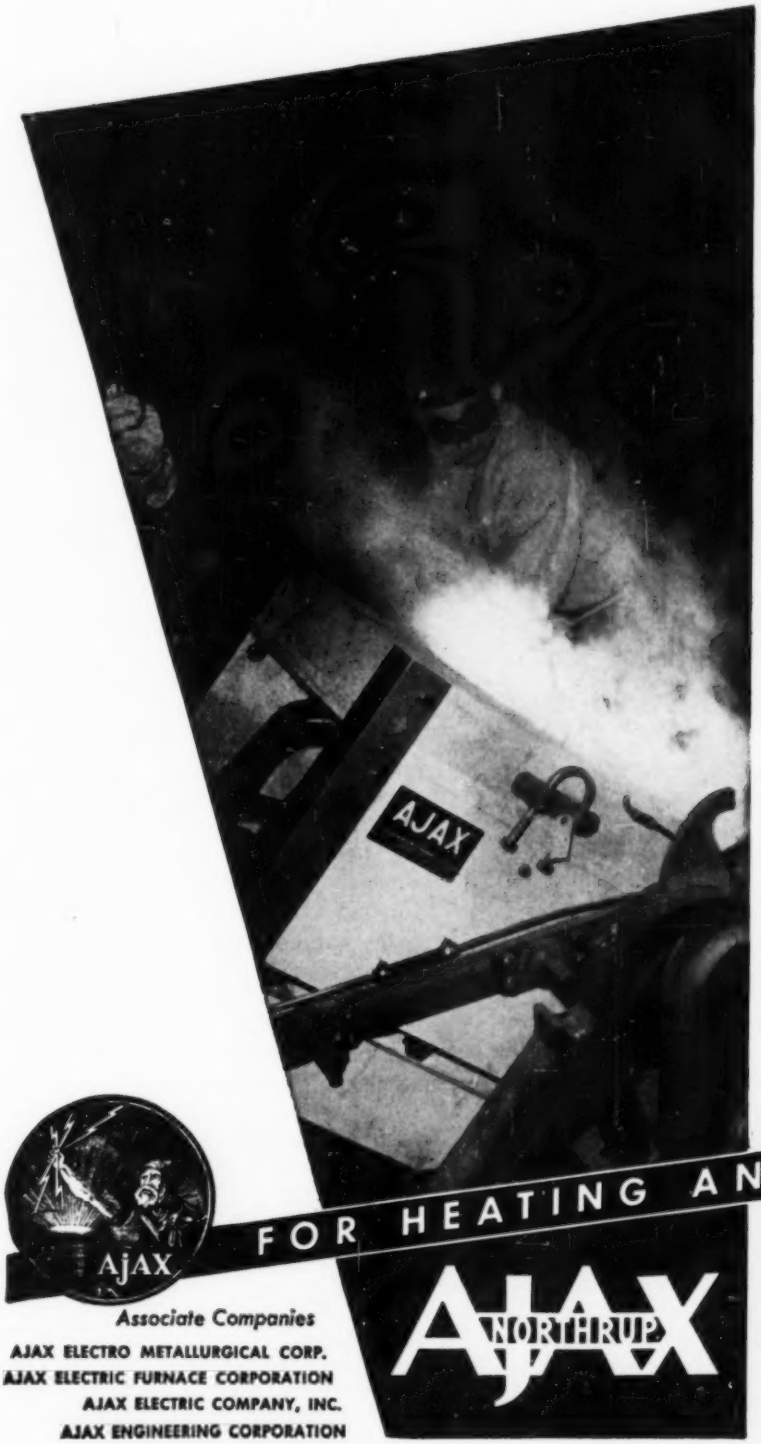
Heat Transfer. *Engineering Research Institute, University of Michigan.* $5.00, 286 pp., 1953.—The book is a compilation of lectures by 11 authorities in the field. It opens with a general discussion of heat transfer problems and in particular the effect on materials of high thermal gradients. Other lectures discuss specific problems that arise when thermal gradients are present in materials ranging from solids through liquid metals, liquids, and gases.

Symposium on Strength and Ductility of Metals at Elevated Temperatures. *American Society for Testing Materials.* $3.25, 249 pp., 1953.—Eight of the 12 papers presented deal with the effects of notches on metals at elevated temperatures, under either static or dynamic loading, and discuss results of current research on the subject. The other four papers deal with metallurgical changes: Recovery and creep in alloy steel, studies of the strength, ductility, and other properties of both low and high alloy steels at elevated temperatures.

Fourth Symposium (International) on Combustion. *The Standing Committee on Combustion Symposia.* $7.00, 926 pp., 1953.—The Fourth Symposium on Combustion took place at the Massachusetts Institute of Technology in 1952. This book is a result of that conference. In addition to papers, unedited discussion remarks are included in the volume. The conference covered flammability; ignition; theoretical and experimental studies on laminar combustion and detonation waves; cellular flames and oscillatory combustion; turbulent flames; quenching, flash back, and blow off; flames of fuel jets; burning of fuel droplets, combustion in rockets and engines; and a round table discussion. There are also nine papers of a survey nature included in the book.

100% Alloy recovery

WITH AJAX-NORTHRUP INDUCTION HEAT



Ajax-Northrup furnaces are famous for their ability to give back what you put into them. They melt *any* metal with minimum losses, at high speeds, and with extremely accurate control of analysis and pouring temperatures.

For example, a foundry using these furnaces to melt stainless steel for corrosion and heat resistant castings reports the following figures on recovery of elements going into the make-up of 18-8 type alloys:

Ni: 100% Cr: 99% Mn: 90%
Si: 94% Mo: 95% Cb: 92%

Another Ajax user saves $60,000 a year just by reducing chromium losses alone. Still another controls pouring temperatures within 20 deg. F., turns out castings so perfect that repair welding has been eliminated.

Ajax-Northrup can save metals and money for you, too. Write us today for details.

SEND FOR NEW INDUCTION HEATING AND MELTING BULLETIN

134

FOR HEATING AND MELTING

AJAX NORTHRUP

Associate Companies

AJAX ELECTRO METALLURGICAL CORP.
AJAX ELECTRIC FURNACE CORPORATION
AJAX ELECTRIC COMPANY, INC.
AJAX ENGINEERING CORPORATION

AJAX ELECTROTHERMIC CORPORATION

AJAX PARK
TRENTON 5, NEW JERSEY

SOMEDAY . . . *it will be for real!*

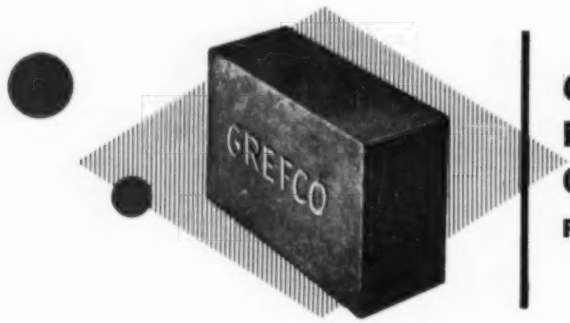
Building with blocks is as much a part of a young boy's life as baseball will be in his teens. Blocks—one on top of the other—to satisfy the typically male urge to create.

As the years roll by, this boy will go on to build bridges or buildings, to make his career in the laboratories of chemical research—or to watch steel being born from ore and earth.

Whatever his future, there will be refractory brick to help him do his job. Blocks of brick to line the furnaces and heat containing vessels—in virtually every step of industry.

There would be no processed raw materials, no production, no living such as we know it but for refractory products which Grefco furnishes in quality and quantity to keep the nation on the move.

To the boy above, a very Merry Christmas and a great many Happy and Prosperous New Years. In his hands lies the future of America.



GENERAL REFRACTORIES COMPANY
Philadelphia

ANOTHER GROUP of Stainless Steel valves used in the operation of this Gulf Coast Refinery.

—yet the Stainless valve is twice as old!

HERE'S photographic evidence of the way Stainless Steel's superior corrosion resistance keeps it in service under severe conditions far longer than other materials.

Both of these end gate valves were in service in one of the pipe stills at a Gulf Coast Refinery. The valve at the left, trimmed with Stainless Steel, is still in excellent condition after two years of service in light Crude Naphtha containing sulfur compounds. But the other valve, made of less durable materials, failed after a year of the same kind of service.

Stainless Steel's ability to stand up under severe service pays off in fewer costly shutdowns, less maintenance and longer equipment life. In many applications, it is far and away the most economical material you can use.

For finest performance, make sure the Stainless you use is perfected, service-tested U·S·S Stainless Steel.

UNITED STATES STEEL CORPORATION, PITTSBURGH · AMERICAN STEEL & WIRE DIVISION, CLEVELAND
COLUMBIA-GENEVA STEEL DIVISION, SAN FRANCISCO · NATIONAL TUBE DIVISION, PITTSBURGH
TENNESSEE COAL & IRON DIVISION, FAIRFIELD, ALA. · UNITED STATES STEEL SUPPLY DIVISION, WAREHOUSE DISTRIBUTORS
UNITED STATES STEEL EXPORT COMPANY, NEW YORK

U·S·S STAINLESS STEEL

USS

SHEETS · STRIP · PLATES · BARS · BILLETS
PIPE · TUBES · WIRE · SPECIAL SECTIONS

3-875

UNITED STATES STEEL

Industrial Notes

• The Committee on Vacuum Techniques, Inc. has been established as a non-profit Massachusetts corporation, embracing membership from industries employing vacuum processes, universities engaged in high vacuum research, and manufacturers of vacuum equipment. The group will attempt to standardize nomenclature, testing techniques, and equipment performance ratings.

• *Rust Furnace Co. has completed a new bar mill furnace, with a second under construction, for the Colorado Fuel & Iron Corp. at the Minnequa Works, Pueblo, Col. Furnaces are of the Rust zone-controlled type, triple fired, and non-recuperative, with a capacity of 60 tons per hr. Both furnaces have inside widths of 20 ft with an effective heating length of 61 ft. They will be equipped for firing with natural or coke oven gas.*

• U. S. Steel Corp. announced that bar mill facilities began operation at the Fairless works in November. Shipment of standard bars and small shapes and concrete reinforcing bars will be made in a limited volume at the outset of operations.

• **Beryllium Corp. of America has placed in operation a new design continuous processing line for beryllium coils and rods. The unit includes a special inert gas generator, electrically heated roller hearth type furnace, and automatic timed reciprocating quench. Installation was made by Continental Industrial Engineers, Inc. Coils up to 36 in. diam will be handled, as will bars up to 2½ in. diam by 20 ft long. Rate will be 2000 lb per hr.**

• *Pittsburgh Steel Co.'s Monessen, Pa., works has placed six new soaking pit furnaces into operation, bringing the total to 12 furnaces that have been added as part of a $3.5 million program covering a total of 15. Final three furnaces are scheduled for operation early next year.*

• Titanium is used extensively throughout the new F-100 super Sabre, latest advance over the F-86 jet used in Korea. Larger than most fighters, the F-100 is 45 ft long, 14 ft high, and has a wing span of 36 ft.

• **The Graham, W. Va. plant of Vanadium Corp. of America has started production of very low carbon ferrochromium, using a process developed by Societe D'Electro-Chimie d'Ugine of France. Vanadium Corp. built a $3.5 million addition to its $8 million Graham plant to produce the new product.**

• Harvey Aluminum announced a new aircraft structural aluminum alloy having typical ultimate mechanical properties of 100,000 psi. After considerable study of alloy chemistry as it affects susceptibility to stress corrosion and mechanical properties, the composition was resolved into the alloy designated as HZM 100.

• *Republic Steel Corp. plans to install facilities at its Massillon, Ohio steel plant that will increase rolling capacity of stainless steel by 1800 tons of finished products per month. Preparations are to start immediately for the installation of a cold rolling mill and auxiliary equipment for cold reducing stainless steel coils.*

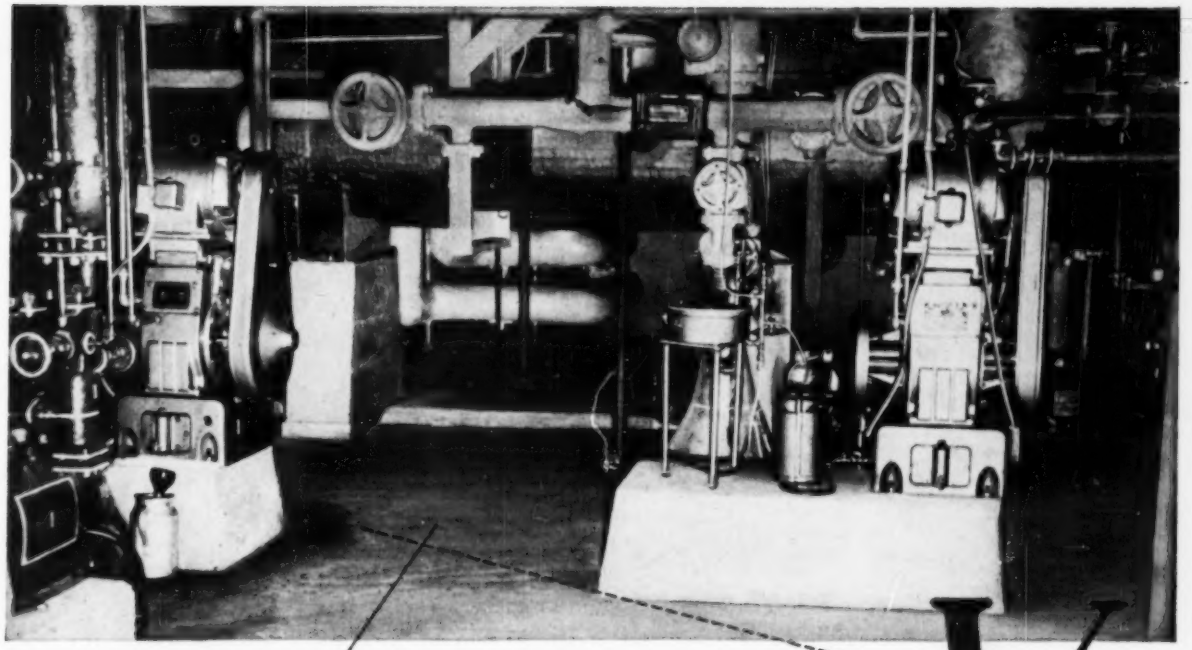
• Aluminum Research Institute has changed its name to Aluminum Smelters Research Institute. The change was made to indicate more clearly the scope of the organization. There will be no change in actual organizational set-up.

• **Titanium output by Rem-Cru Titanium, Inc., at its Midland, Pa. plant will be stepped up 300 pct during the first six months of 1954. Rem-Cru expects to turn out 10 ingot tons of titanium per day by the early part of next year.**

NEW BUEHLER CATALOG

200 pages — a comprehensive catalogue of Buehler equipment for the metallurgical laboratory. Includes sections on Cutters, Grinders, Specimen Mount Presses, Polishers, Metallographs, Microscopes, Cameras, Testing Machines, Spectrographs, Furnaces and other equipment for the metallurgical laboratory.

Buehler Ltd. METALLURGICAL APPARATUS
A PARTNERSHIP
165 West Wacker Drive, Chicago 1, Illinois



Stokes Microvac Pumps in machine room at Research Laboratories, Inc., St. Joseph, Mo., including diffusion type booster pump, condenser, and oil clarifier. Note relatively small size of the Stokes 8" Vacuum Valve (top-center) compared with other 6" vacuum valves at right and left.

Stokes Microvac Pumps... basic to Vacuum Processing

High volumetric and mechanical efficiency makes these famous pumps economical and reliable units in any vacuum system.

Capacities of Stokes Microvac Pumps run from 15 to 500 cfm . . . pressures to 10 microns absolute. Power consumption is low and the top-mounted motor contributes to compact design requiring minimum floor space.

Lubrication of the four moving parts (including the exhaust valve of corrosion-resistant Teflon) is fully automatic. There are no stuffing-boxes or grease-fittings, and no packing.

Parts are precision-finished, standard and interchangeable. Freedom from wear assures years of trouble-proof service.

Stokes is the only manufacturer of equipment for complete vacuum systems, including Microvac mechanical pumps, oil diffusion pumps, McLeod Gages and Vacuum Valves.

Consult with Stokes on the application of vacuum to vacuum sintering, melting, de-gassing, heat treating, inert gas purging, vacuum metallizing, and to other purposes for which vacuum deserves exploration.

F. J. STOKES MACHINE COMPANY, PHILADELPHIA 20, PA.

Send for new Vacuum Calculator for rapid slide-rule calculations. Includes standard ABCD log scale. Also send for Catalog 700, "Stokes Microvac Pumps for High Vacuum," with capious reference material.

STOKES

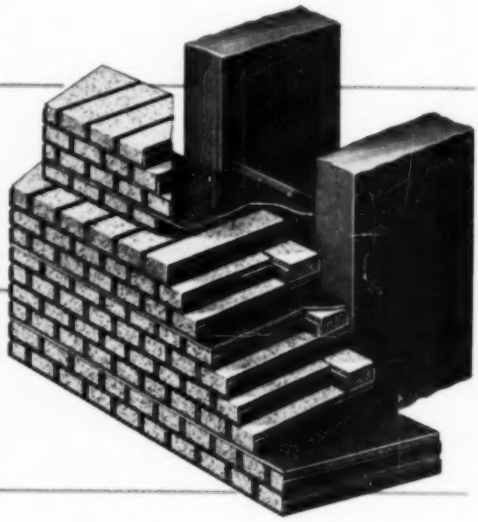
STOKES MAKES: High Vacuum Equipment, Vacuum Pumps and Gages / Industrial Tabletting, Powder Metal and Plastics Molding Presses / Pharmaceutical Equipment

HARBISON-WALKER

CHROMEX B—an extremely hard fired chrome-magnesite refractory having unusual constancy of volume and strength at high temperatures.

METALKASE—the pioneer metal-encased basic brick possessing an unusual combination of desirable properties.

CHROMEX—a chemically-bonded chrome-magnesite brick having excellent spalling resistance.



MAGNEX—a chemically-bonded magnesite-chrome brick—highly basic and of low spalling tendency.

Typical section of open-hearth furnace front wall built of METALKASE. For maximum stability steel plates are used at every fourth course vertically. These are tack-welded to steel bars which in turn extend behind the buckstay and are free to move vertically.

H-W MAGNESITE—the standard burned magnesite refractory for more than half a century.

THERMAG—a hard burned magnesite-chrome refractory possessing enhanced physical properties.

H-W CHROME—a hard burned chrome brick especially adapted for various specific uses.

FORSTERITE—the only commercially produced magnesium-silicate brick—suited for certain particular applications.

H-W PERIKLASE—an exceptional high-magnesia brick of unusual high-temperature stability.

OTHER HARBISON-WALKER BASIC REFRACTORIES

H-W Magnamix
H-W Washington Dead Burned Magnesite Grains
H-W Washington Furnace Magnesite
H-W Special Furnace Chrome
Plastic Thermolith Batch
Thermolith and Other Cements

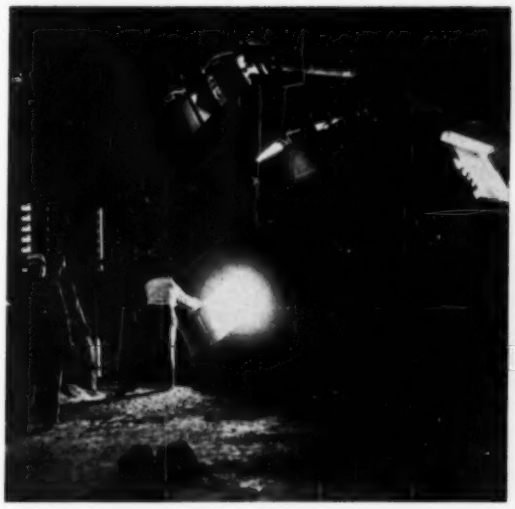
BASIC REFRACTORIES

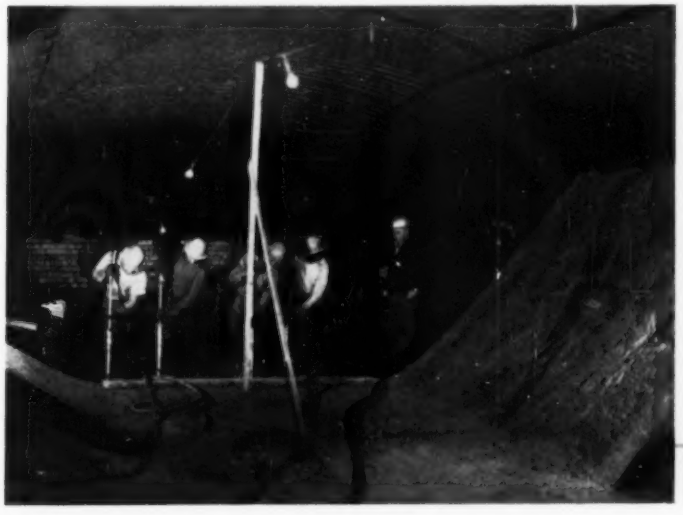
serve the varied and specialized needs for metallurgical furnaces

Shown at the left are the various brands of Harbison-Walker basic refractories. They include classes especially suited for each particular need in furnaces for smelting ores, refining metals and manufacturing alloys.

Among the brands listed here are types and classes established as standards for furnaces employed in the metallurgy of ferrous and non-ferrous metals and alloys.

The superior performance of Harbison-Walker basic refractories is the result of: (1) a thorough knowledge of the requirements gained through close cooperation with producers of metals and alloys; (2) extensive and continuous original research; and (3) the use of top quality raw materials processed in modern plants under close laboratory control. Harbison-Walker uses the most up-to-date methods and equipment to insure the quality and dependable uniformity of basic refractories.





(*Above*) In basic linings of electric furnaces, METALKASE are used in the upper side walls and provide maximum resistance to spalling and to slagging action. Lower side walls and subbottom are built of H-W MAGNESITE. MAGNAMIX or H-W DEAD BURNED MAGNESITE forms the monolithic banks and bottom.

(*Left*) H-W MAGNAMIX bottom section in a new open-hearth furnace. Air hammers are used to ram the material into a dense, monolithic working hearth of the desired thickness and contour.

HARBISON-WALKER REFRACTORIES CO.

AND SUBSIDIARIES

World's Largest Producer of Refractories

GENERAL OFFICES • PITTSBURGH 22, PENNSYLVANIA

WITH the statement that "the atomic energy industry of the United States knows how to build nuclear power plants that will work," John R. Menke, president of Nuclear Development Associates, Inc., presented the case for civilian use of atomic power. He spoke at the recent Second Annual Conference on Atomic Energy sponsored by the National Industrial Conference Board. He pointed out that there were many shades of opinion and many reactor design variations for which a good case could be made.

Mr. Menke divided problems in the search for design solutions into five categories: neutron and raw material economy; processing of spent fuel; capital cost and return on investment; safety; and difficulty or immediacy of achievement.

He rates the graphite moderated reactor as one which is poor in neutron economy. It is also poor in processing because of its multitude of solid fuel rods which are difficult and expensive to fabricate and handle. Mr. Menke rates this reactor as intermediate in capital cost, poor in expected revenue and intermediate in safety. But it is one that can be built now. He sees little promise for it in the future in the long run.

He sees the homogeneous reactor as low in neutron economy but best in processing in capital cost. He states that "it should be intermediate in revenue and safety." Mr. Menke sees it as an attractive proposition at this time.

The fast reactor he rates as very good in neutron economy and revenue. Its processing rating, as he sees it, is poor at this time. Its least known factor is the safety one. Should it prove to be unsafe, justification for building this reactor on economic grounds would be difficult.

◆◆◆◆◆◆

PENNSYLVANIA Coal & Coke Co., and the Eagle-Picher Co. have turned pessimistic in their attitude toward extraction of germanium from coal. Both companies have been following extensive research programs. They have analyzed hundreds of samples of coal from widely separated deposits—finding almost nothing. Their conclusions have been reached reluctantly, but Eric Mitchel, vice-president for operations of Pennsylvania sums up his firm's efforts this way: "Actual analysis of germanium in coal showed no justification for going after it. But this does not mean we will stop hunting. Meanwhile recovery is best from fly ash. We must change our optimism so far as coal deposits are concerned." Meanwhile, the Pittsburgh office of the Bureau of Mines continues to experiment with germanium from coal in an assist play for the Signal Corps.

A. P. Thompson, Eagle-Picher director of research, whose firm combined research forces with Pennsylvania Coal in the hunt for germanium-bearing coal, said: "There is no question but what too bright a picture has been painted with respect to the profitable recovery of germanium from coal. Frankly, under present economic conditions and taking into consideration the many factors involved, even under the best conditions, coal does not appear a likely source of germanium."

Mr. Thompson based the attitude of his firm on certain factors: Not all coals contain germanium and research has disclosed that content at best is low and distribution erratic through the vertical and lateral extent of the seam; germanium tends to be concentrated in the top or bottom two or three in. of the seam, but concentrations are too low and spotty to warrant selective mining; the best coals rarely show more than 0.002 or 0.003 pct germanium, so small that direct recovery would not be practical; the extremely small quantities of germanium in coal makes it almost absolutely necessary that germanium be recovered as a byproduct after utilization of the caloric content of the coal; germanium extraction from coal combustion is expensive and difficult, and involves high losses at every step; and the germanium market is unstable, seeming to decline at present.

◆◆◆◆◆◆

WHEN Benjamin J. Fairless and the late Philip Murray signed the contract which brought peace to the embattled steel industry last year, they also agreed to something new in labor relations. The contract stipulated that the head of the United Steelworkers of America and Mr. Fairless, chairman of the board of U. S. Steel Corp., would make joint plant visits. The visits were designed to make possible a better understanding at plant levels between management and the union. Visits began in November with Mr. Fairless and David J. McDonald, USW president, visiting U. S. Steel plants in the Cleveland-Lorain district and the Pittsburgh area. Plans are being made for other trips. In announcing the trips Mr. Fairless and Mr. McDonald agreed that "there is no better way to look over our mutual problems in hopes of developing a better relationship and a better understanding of each other in just this way."

In addition to management members of both U. S. Steel and USW organizations, local Union officers and Grievance Committee men will participate. Announcement of the tour came jointly from U. S. Steel and the USW.

◆◆◆◆◆◆

WILL steel production go up, down, or stay about the same? Predictions are as plentiful as there are analysts. One steel man predicts that operations for the remainder of 1953 will be at capacity. He is Benjamin F. Fairless of U. S. Steel. Mr. Fairless makes further prediction that U. S. Steel operations for the first quarter of 1954 will be at about 95 pct of capacity.

In the report on U. S. Steel operations at the end of the third quarter, Mr. Fairless noted that the

company is nearing completion of two of its major projects. The Fairless works at Morrisville, Pa. will be practically complete by the end of 1953. Ingot output is currently at about 75 pct of the rated capacity of 1.8 million tons. Cerro Bolivar, mammoth Venezuelan iron ore development, will start shipping around the first of the year. Total for 1954 is expected to be 2 million tons with the annual rate at year's end around 5 million tons.

In comparison to the optimistic note sounded by Mr. Fairless, Jones & Laughlin Steel Corp. announced that November production was cut 9 pct. J&L furloughed between 300 and 350 of its 44,000 employees. Five of the 22 open hearths and one of six blast furnaces were shut at its Pittsburgh works. Recently, J&L cut back on tin mill operations, laying off 350 men at Aliquippa, Pa.

◆◆◆◆◆◆

AT the Philadelphia Regional Technical Meeting of the AISI held Dec. 3, 1953, L. F. Reinartz and H. C. Barnes, vice-president and consulting metallurgist respectively of Armco Steel Corp., presented a comprehensive paper: *Electric Furnace vs Open Hearth Furnace in Cold Metal Shops.* This paper should be of special interest to small steel shop operators who are often faced with the problem of what type of furnace to install to insure economic production of small tonnages. The authors cover very thoroughly the cost comparisons between the electric and open hearth furnaces for plants producing 250,000 and 500,000 tons of steel per year. In choosing this range the authors state that a steel plant with a capacity of 250,000 tons per year is the smallest which can be competitive, and for a capacity above 500,000 tons per year an integrated steel plant with one or more blast furnaces to supply hot metal is indicated. The range selected, therefore, is that in which the electric furnace has the best chance to compete with the open hearth.

The cost factors for the two methods are discussed under the following headings: A—Operating costs, B—material costs, C—installation costs and capital charges, and D—total ingot costs. These are itemized for the two sizes of plants. One size, the 250,000 ton per year shop, is equipped with either three 150-ton open hearths or three 60-ton electric furnaces; the other size, the 500,000 ton shop, is equipped with either four 225-ton open hearths or four 90-ton electric furnaces.

In their summary and conclusions Reinartz and Barnes presented the following important facts:

A—The operating cost of electric furnaces is about $4.00 per ton of ingots higher than that of open hearth furnaces due primarily to more expensive fuel and the high cost of electrodes.

B—The material cost for electric furnace steel is about $4.00 per ton less than for open hearth steel based on Pittsburgh prices of pig iron and scrap. With cheap scrap the material cost for electric furnace steel may be as much as $8.00 or $9.00 per ton less than for open hearth steel. With cheap pig iron the material costs for the two processes are about equal.

C—The installation cost and capital charges of electric furnace shops are about 60 pct of those of open hearth shops of similar capacity.

D—The overall cost of ingots after fixed charges is $2.60 to $4.00 less from electric than from open hearth furnaces with Pittsburgh prices for pig iron and scrap, but the lowest electric furnace cost is still higher than the quoted Pittsburgh price of ingots. With cheap scrap the cost of ingots may be $7.00 or $8.00 less from electric than from open hearth furnaces. This may be $3.00 to $6.00 less than the Pittsburgh price of ingots and $36.00 to $39.00 less than the price of ingots quoted in some places. With cheap pig iron the cost of ingots is about the same from electric and open hearth furnaces and higher than the quoted Pittsburgh price.

E—The availability of ample quantities of cheap scrap is the most important factor in determining suitable locations for low cost ingots from electric furnaces. In suitable locations for small tonnages in cold metal shops the electric furnace can beat the open hearth in the production of lower cost ingots with a smaller capital expenditure.

◆◆◆◆◆◆

THE suggestion box has become an important part of the engineering operations of many of the nation's leading industrial plants. Out of it have arisen ideas that have saved thousands of dollars—and conversely made thousands of dollars for employees who dropped the suggestions through the slot. A recent limited survey by the National Assn. of Suggestion Systems showed that almost 200 employers are giving about $7 million this year in awards. The awards range from $3 to several thousands and from clocks and sedans to baseball tickets.

General Motors, Inc., one of the leading exponents of the plan, presented its employees with $1,860,148 during the first nine months of 1953. The total for 1952 reached $1,678,372. Of the 1,079,796 suggestions submitted by General Motors employees through September, about 25 pct were put to work.

Westinghouse Electric estimates that it saved $1.1 million last year through employee suggestions. Payment to employees amounted to $145,000. Recently, the company doubled the size of the awards. One criticism of the suggestion box system is that the suggestions substitute for competent research and planning. To this, Gwilym A. Price, Westinghouse president says: "The man closest to the job is often in the best position to find a better way, despite competent methods men, research engineers, and alert supervisors."

Hidden costs of implementing the suggestions, some feel, are offset to a large degree by gains in safety, working conditions, product development, and sales methods. A lot of public relations is needed to get the suggestions flowing into the boxes. Once the program gets underway, however, employees usually take it seriously—and the poison pen notes disappear.

Drift of Things

AS a Christmas present to the Editors we are contributing a few paragraphs this month to our old love, "The Drift of Things," knowing by experience how welcome some copy to fill a yawning hole in the makeup can be. We think that the ideas we are about to put down on paper should be a valuable gift to the officials of mining and metallurgical companies as well. Not an outright gift, because it will cost the companies something to carry out our proposal, but if they make the investment we think it will pay big dividends.

At the Dallas meeting of the Petroleum Branch, in October, a record attendance was registered—some 1760 men, and an estimated 600 to 700 ladies. We were struck by the fact that such a large ratio of ladies was present and also by the fact it was a youthful crowd, a large proportion plainly being in their twenties and thirties. Remarking on these observations we were told that a great many of the companies had been exceedingly liberal in allowing their younger operating men to attend the meeting—not just allowing them to go, either, but sending them, paying their expenses, *including their wives.*

Now the business acumen of the oil companies' management is well known. They have plenty of ideas and in general they pay off. Money is freely spent, but only when there is a good chance that such spending will ultimately mean higher earnings for the company. Every investor in oil stocks in the last decade or two knows how successful they have been.

Investment of a few hundred dollars a year in increasing the technical competence and the professional stature of a young employe, to say nothing of building up his morale and his loyalty to the company, will pay high dividends. A raise in salary is considered more or less routine, but a trip to an important meeting of his professional society, with all expenses paid, is a gift of the gods, an unexpected reward that makes possible fulfillment of an ardent wish. The young man is getting the same privilege as the top brass.

In about two months, the Annual Meeting of the AIME will be held in New York. There will be four full days of opportunity to attend technical sessions and to rub shoulders with those who are engaged in a common professional field. Among the 300-odd papers are some that come close to home to practically every AIME member. Much of the discussion will never be printed. The most valuable discussion is often never even heard in public. What pays off best is what is learned in the corridors and the private rooms. You tell somebody what you are trying to do. He tells you he has tried that and it won't work. He tells you a better way, and makes you a sketch. When you later find that his way won't work either you write him a letter, or call him on the phone, or visit his plant. Between you the problem is solved. By going to the meeting, *you know whom to approach.*

A young man can in many respects get more out of a meeting than an older man. His mind is open and fresh. He needs to know more people, and if he is well coached he will meet them. He will come back with many new ideas, any one of which may well turn out to be worth many times the cost of sending him to the convention. Some excellent advice on how to make the most out of attendance at a professional gathering was published on these pages in January 1949 in an article by Herb Rose entitled "Getting Your Money's Worth." Reprints are available on request.

Time was when a trip to and from New York from a Western mining district took more time than did the actual meeting itself. Now, one can travel from Los Angeles to New York in 7¼ hr. A week, at most, is all that is required to go from almost any place in North America and take in the entire AIME Annual Meeting. Few men are so necessary to a company's operation that they cannot be spared for that length of time. Suppose they had the flu or something.

Once we heard an executive say that if he sent his younger men to meetings he would lose them—they would get better jobs. If a man seeks another job it is usually because he is dissatisfied where he is, and if that is the case he will leave sooner or later anyway unless the company removes the causes of his dissatisfaction. If a man is loyal to his employer, happy in his work, and merely succumbs to a better offer from someone else, no self-respecting employer should stand in the way of his advancement. He might ask himself if that is not the way he, too, got ahead in the profession.

Some young men have complained to us that they were not permitted to attend an AIME meeting even if they paid their own expenses. Certainly it is hard to see how a man could accomplish less in four days at a meeting than in continuing routine work. Some employers permit a man to attend but at his own expense. This bars most young men with families from coming to New York, so if he is to profit from the opportunity the young man must have some pocket money. The really far-sighted employer will pinch present pennies and sacrifice later dollars. On the week end of December 20 he will review which members of his staff deserve and are likely to get the most out of coming to the Annual Meeting. On Christmas morning he will call them up. "Merry Christmas, Bill," he will say; "I have decided that you and Mary should represent us in New York for the AIME February meeting. I believe the ideas you will get and the contacts you will make will prove that your trip is a good investment for us. I will send you a paper on how to get the most out of the meeting. When you get back you can give us a little report."

Bill will think that's the finest Christmas present he ever got. He will do his utmost to see that the company's confidence in him has not been misplaced. He will be convinced that he works for a fine company and that his boss has his eye on him. Don't tell us that those few hundred dollars will have been unwisely spent!

E. H. Robie

Here's a specialty steel maker who doubled sidewall life with a BRI Gun

THE Ingersoll Steel Division of Borg-Warner, operating two 7-ton electric furnaces, recently bought a BRI Gun. It is used between heats for quick repair of furnace sidewalls with Gundol.

Lining life, according to the Melting Superintendent, used to average about 85 heats. Now it averages better than double that figure. For instance, since the last relining job, one of the furnaces has finished a run of 194 heats. The saving in refractory costs is significant, and even more important, the elimination of shutdowns for frequent relining adds materially to steel production.

With two more furnaces soon to be installed, the company plans to standardize sidewall maintenance, using Gundol with the BRI Gun.

This is one more example of the practical value of our gun refractories. Long since found essential for large furnace maintenance, Gundol and Gunmix are now proving just as economical for use in smaller furnaces.

So if you operate electric furnaces, large or small, we believe you will be interested in the economies to be realized through the use of a BRI Gun and gun refractories in your shop.

Basic Refractories Incorporated 845 HANNA BUILDING, CLEVELAND 15, OHIO

Exclusive Agents in Canada: REFRACTORIES ENGINEERING AND SUPPLIES, LTD., Hamilton and Montreal

DUCTILE IRON GEARS provide *Superior Strength* with *Excellent Resistance to Wear*

Large Gears... such as these Ductile Iron girth gears drive large tube mills in the cement and mining industries. Put into service without heat treatment, they normally provide 92,000 to 100,000 psi ultimate tensile strength, 3 to 5% elongation, and 270-290 BHN on the tooth surface.

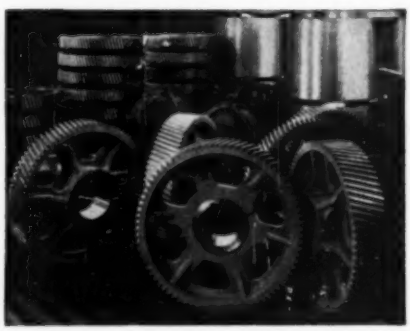
In addition to excellent castability, ready machinability and moderate cost, Ductile Iron offers properties that are vital in a gear material.

For along with high strength and measurable ductility, Ductile Iron "as cast" combines good resistance to wear and galling, with superior values for notched endurance limits.

Ductile Iron can be heat treated to provide tensile strengths of over 150,000 psi. It develops surface hardnesses of over 600 BHN after flame or induction hardening. Service data show also that annealed Ductile Iron develops impressive properties which result in peak performance.

Ductile Iron can provide a chilled, carbidic, abrasion-resistant surface supported by a tough ductile core. No other single material combines these properties. Still another advantage is its ability to damp out vibrations that otherwise might build up stresses to dangerous levels.

Send us details of your prospective uses, so that we may suggest a source of supply from some 100 authorized foundries now producing Ductile Iron under patent licenses. Request a list of available publications on Ductile Iron ... mail the coupon now.



Medium Gears produced in heat treated Ductile Iron have replaced steel gear castings and forgings in papermaking and allied equipment. Annealed Ductile Iron can be machined at a rate of 2 to 3 times that of good quality gray iron of comparable hardness.

The International Nickel Company, Inc.
Dept. 20, 67 Wall Street, New York 5, N. Y.

Please send me a list of publications on: **DUCTILE IRON**

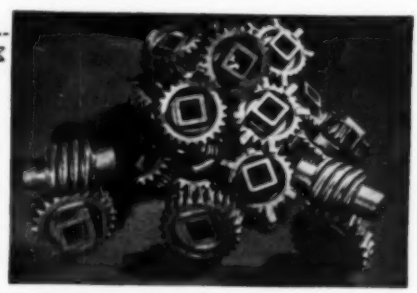
Name_____ **Title**_____

Company_____

Address_____

City_____ **State**_____

JM 12-53



Small Gears... also worms ... exemplify an application of Ductile Iron in the railroad field.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

A new iron-base alloy, developed as a substitute for stainless steel in reinforcing braid of Signal Corps lightweight communications cable, was announced by H. O. McIntyre and George Manning, both of Battelle Memorial Institute. The alloy substitutes manganese and copper for all nickel and chromium used in the original reinforcing wire braid.

Dow Chemical Co. started initial operations of the first high speed, high production rolling mill for magnesium at its Madison, Ill., plant. The mill is an 84-in. reversing breakdown coil unit. It produces hot rolled plate 6 ft wide and in lengths up to 60 ft from 2000-lb rolling ingots.

Two new furnaces, part of a battery of six, were lit at the Wah Chang Corp., tungsten refinery at Glen Cove, L. I. Plant capacity is being kept a military secret. According to Kuo Ching Li, the plants were built to meet wartime requirements and "...we plan to use only one of these furnaces in the measurable future for we look forward optimistically to a real and lasting peace."

Construction of the explosives processing and assembly plant on the Spoon River 18 miles east of Macomb, Ill., has been called off by the Atomic Energy Commission. The Commission stated that technical developments will permit existing plants to turn out the same products as would have come from the cancelled $26 million facility.

The USSR is boasting that aluminum supplied to the holloware industry during 1953 amounted to 40,000 metric tons, or more than total production in 1937. Washington observers estimate current Russian aluminum production rate to be 300,000 tons. With a holloware goal of 107,000 tons in 1955, experts think Russia is aiming at a total production of 455,000 tons for that year. Current rate of military aluminum consumption in Russia is figured to be 250,000 tons.

Zirconium Corp. of America has been formed to produce zirconium oxide, and other zirconium compounds. Products will be manufactured under a patented process developed by Sylvester & Co., of Cleveland. A new plant is being completed at Solon, Ohio, after more than a year of successful pilot plant operation.

Contracts have been signed between Barium Steel Corp., and Innocenti, S. G. of Milan, Italy for specialized equipment for the U. S. corporation's new seamless tube mill at Phoenixville, Pa. The plant will use the process developed by Albert Calmes of Milan. The process will alloy closer operating tolerances resulting in a superior product both in uniformity of wall thickness and surface finish. Innocenti has built similar mills in Germany, Belgium, Sweden, and Italy.

Substantially reduced railroad freight rates for iron and steel from all eastern territory points to all points in southern territory have been filed with the Interstate Commerce Commission and are now effective.

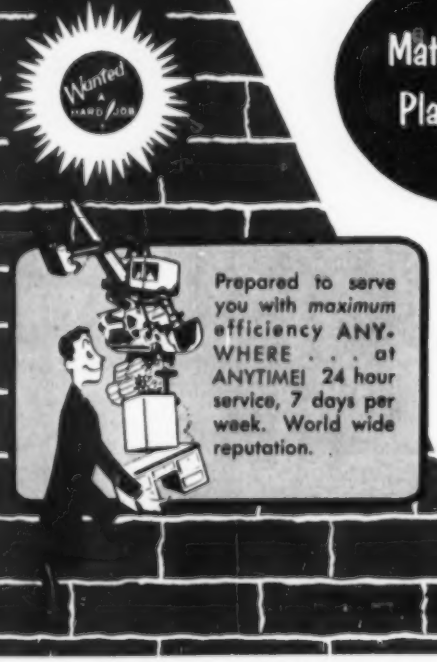
"KNOW-HOW"

to do an
expert job!

All Types of Masonry
Excavation and
Foundation Work

Material Handling
Plant Maintenance

Furnace Tearouts
Salamander and
Slag Removal



Prepared to serve you with *maximum* efficiency ANY-WHERE . . . at ANYTIME! 24 hour service, 7 days per week. World wide reputation.

Serving the Steel Industry for Over 30 Years

CHICAGO CONCRETE BREAKING CO.

EDWARD GRAY, *President*

GENERAL OFFICES
12233 Avenue O, Chicago 33, Ill.
BAyport 1-8400

PITTSBURGH 19, PA.
550 Grant St., Suite 704
ATlantic 1-4674

ON YOUR NEXT BLASTING PROBLEM!

For the story of FERROCARBO in quality steelmaking, mail the coupon today—or phone or write the FERROCARBO distributor nearest you. You'll learn why steel deoxidized with FERROCARBO is "plus steel."

KERCHNER, MARSHALL & CO.
PITTSBURGH • Cleveland • Buffalo
Philadelphia • Birmingham • Los Angeles

MILLER & COMPANY
CHICAGO • St. Louis • Cincinnati

WILLIAMS & WILSON
TORONTO • Montreal • Windsor

THE CARBORUNDUM COMPANY, Dept. JM 84-31
Niagara Falls, New York

Gentlemen:

I would like to have the FERROCARBO story—no obligation on my part.

NAME AND TITLE

COMPANY

STREET AND NUMBER CITY ZONE STATE

FERROCARBO

TRADE MARK

by CARBORUNDUM

"Carborundum" and "Ferrocarbo" are trademarks which are registered in the U. S. by The Carborundum Company, Niagara Falls, New York, and in Canada by Canadian Carborundum Company, Ltd., Niagara Falls, Ontario.

. . . there are NOW

ALLOYING MATERIALS ENOUGH

for all needs

SHORTAGES of important metallurgical additives have now been either directly relieved or compensated by satisfactory alternatives.

MOLYBDENUM: Filing melt sheets is no longer necessary. Molybdenum Production is now great enough to supply everyone. Government restrictions have been eliminated.

TUNGSTEN: Restrictions are now eliminated on Tungsten, too. New production and resulting growth of stock piles have brought relief. Tungsten is readily available.

BORON: The potency of Boron as an intensifier of the effects of other alloying materials, is now well recognized. Very minute additions can be substituted for considerable percentages of scarcer and more costly elements, with full maintenance of the hardenability and other essential properties of high-grade steels.

The problem of an economical and satisfactory form in which to introduce Boron is met by Ferro Boron produced by the Molybdenum Corporation.

RARE EARTHS: Operating the world's largest rare earth deposits, the Molybdenum Corporation of America has recently conducted extensive pioneering research in evaluating the properties, applications and uses of RareMeT Compound.

For example, in stainless steel, excellent results have been demonstrated in hot workability and increased shipping yield. In nodular iron, small additions of rare earths have helped to produce consistently good ductility by counteracting tramp elements such as lead and titanium.

Write today for free Progress Report Number 1, "Rare Earths in Melting." Just off the press!

MOLYBDENUM

CORPORATION OF AMERICA

Grant Building **Pittsburgh 19, Pa.**

Offices: Pittsburgh, Chicago, Detroit, Los Angeles, New York, San Francisco

Sales Representatives: Edgar L. Fink, Detroit; Brumley-Donaldson Co., Los Angeles, San Francisco

Subsidiary: Cleveland Tungsten, Inc., Cleveland *Plants:* Washington, Pa., York, Pa.

MCA

Electric Furnace Steel Committee

Executive Committee

W. M. Farnsworth, Chairman
Republic Steel Corp., Massillon, Ohio
R. H. Frank, Past-Chairman
Bonney-Floyd Co.
C. W. Briggs
Steel Founders' Society of America
Gerhard Derge
Carnegie Institute of Technology
M. E. Goetz
Republic Steel Corp.
J. S. Marsh
Bethlehem Steel Co.
Ernest Kirkendall, Secretary
AIME, New York
M. J. Meinen
Universal-Cyclops Steel Corp.
A. J. Scheid
Columbia Tool Steel Co.
C. F. Staley
Armco Steel Corp.
R. J. Wilcox
Michigan Steel Casting Co.
Clyde Wyman
Burnside Steel Foundry Co.

W. M. FARNSWORTH
Chairman
Executive Committee

Conference Committee

F. O. Lemmon, Chairman
Ohio Steel Foundry Co., Springfield, Ohio
Samuel Arnold, III
American Bridge Co.
J. H. Baldrey
Cooper Alloy Foundry Co.
L. W. Cashdollar
Union Electric Steel Corp.
D. L. Clark
Simonds Saw & Steel Co.
William Doyle
Pittsburgh Steel Foundry Corp.
J. E. Harrod
U. S. Steel Corp.
R. H. Jacoby
Key Co.
H. F. Walther, Vice-Chairman
Timken Roller Bearing Co.
Paul Lindberg, Jr.
McLouth Ste. l Corp.
C. G. Mickelson
American Steel Foundries
Frank St. Vincent
Vanadium Corp. of America
C. E. Sims
Battelle Memorial Institute
Alex C. Texter
Atlas Steels Ltd.
Frank Weir
Harbison-Walker Refractories Co.
V. E. Zang
Unitcast Corp.

R. H. FRANK
Past-Chairman
Executive Committee

Finance Committee

R. K. Kulp, Chairman
Electro Met. Co., UCC
W. M. Charman, Jr.
Ferro Engineering Co.
V. J. Nolan
National Carbon Co., UCC
H. E. Orr
Vanadium Corp. of America

Committee on Arrangements

W. P. Albaugh, Chairman
Miller & Co., Cincinnati
C. T. Haller
International Nickel Co.
J. J. Meckes
International Graphite & Electrode Corp.
E. J. O'Neal
Newport Steel Corp.
Frank Weir
Harbison-Walker Refractories Co.

Membership Committee

T. J. McLoughlin, Chairman
U. S. Steel Corp.
W. M. Farnsworth
Republic Steel Corp.
V. J. Nolan
National Carbon Co., UCC
Clyde Wyman
Burnside Steel Foundry Co.

EFSC Attendance

1943	414	1948	534
1944	569	1949	585
1945	500	1950	620
1946	546	1951	752
1947	569	1952	823

F. O. LEMMON
Chairman
Conference Committee

Technical Program

Electric Furnace Steel Conference

Hotel Netherland Plaza, Cincinnati

THURSDAY, DECEMBER 3

9:30 to 9:45 am—Pavillon Caprice

GENERAL SESSION

Welcoming Remarks:

By F. O. Lemmon, Chairman, Committee for the Eleventh Annual Conference

Response:

By W. M. Farnsworth, Chairman, Electric Furnace Steel Executive Committee Announcements and Reports

INDUCTION STIRRING IN ARC FURNACES

Chairman:

D. J. Girardi, Research Metallurgical Engineer, Timkin Roller Bearing Co., Steel & Tube Div., Canton, Ohio

1. **Introduction**

   Paper by H. F. Walther, Melting Superintendent, Timken Roller Bearing Co., Steel & Tube Div., Canton, Ohio

2. **The Development of Induction Stirring**

   Preprinted paper by Eric G. Malmlow, President, Aros Electric Inc., New York, N. Y.

3. **Manufacture of the Timken Stirrer**

   Paper by Quentin Graham, Vice-President, The Elliott Co., Ridgway, Pa.

4. **Arc Furnace Rotating Type Magnetic Stirrer**

   Paper by E. H. Browning, Industrial Engineer and M. F. Jones, Design Engineer, Westinghouse Electric Corp., E. Pittsburgh, Pa.

5. **General Discussion**

2:00 to 5:00 pm—Pavillon Caprice

JET ENGINE STEELS AND RELATED OPERATING PROBLEMS

Chairmen:

L. W. Cashdollar, Chief Metallurgist, Union Electric Steel Corp., Carnegie, Pa.

Jack Atkinson, Melting Superintendent, Dominion Foundries & Steel Co., Hamilton, Ont., Canada

1. **Application and Manufacture of High Strength and High Alloy Steels for the Jet Engine Program**

   A. Application
   Paper by I. Perlmutter, Director, Research Div. Materials Laboratory, Wright-Patterson Air Force Base, Ohio
   Paper by R. B. Johnson, Jr., Engineer, Aircraft Gas Turbine Div., General Electric Co., Evendale, Ohio

   B. Manufacture
   Paper by S. B. Batdorf, Manager, Development Div., Materials Engineering Dept., Westinghouse Electric Corp., E. Pittsburgh, Pa.

2. **Slag Treatment for Conservation of Chromium**

   Preprinted paper by T. W. Merrill, Chief Metallurgical Engineer, Vanadium Corp. of America, New York, N. Y.
   Discussion by Adam Texter, Melting Superintendent, Firth Stirling Steel & Carbide Corp., McKeesport, Pa.

3. **Rapid Bath Analysis**

   A. Spectrographic Analysis
   Preprinted paper by George C. Delplace, Chief Chemist, Rotary Electric Steel Co., Detroit, Mich.
   Preprinted paper by Harold C. Brown, Spectrochemist, Armco Steel Corp., Butler, Pa.

   B. Validity of Results of Rapid Method of Analysis
   Preprinted paper by M. L. Windle, Chief Chemist and William Magrun, Spectroscopist, Simonds Saw & Steel Co., Lockport, N. Y.

4. **Measurement of Electric Furnace Bottom Shell Temperature**

   Paper by D. G. Harris, Metallurgical Research Dept., Republic Steel Corp., Canton, Ohio
   Paper by H. C. Bigge, Superintendent No. 1 O. H. & Tool Steel, Bethlehem Steel Co., Bethlehem, Pa.

FRIDAY, DECEMBER 4

9:30 am to 12:30 pm—North Hall

INCLUSIONS IN STEEL

Chairman:

Clyde Wyman, Chief Metallurgist, Burnside Steel Foundry Co., Chicago, Ill.

1. **Deoxidation and its Effects on the Physical Characteristics of Steel**

   Preprinted paper by Charles Christopher, Director of Research, Continental Foundry & Machine Co., E. Chicago, Ind.
   Discussion by C. E. Sims, Assistant Director, Battelle Memorial Institute, Columbus, Ohio
   Discussion by C. K. Donoho, Chief Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

2. **Observations of Sulphide and Oxide Formation in Steel**

   Paper by Walter Crafts, Assoc. Director of Research and D. C. Hilty, Research Metallurgist, Metals

ANNUAL DINNER

Thursday, December 3

6:30 pm—South Hall, Reception and Cocktail Party for dinner guests

7:30 pm—Hall of Mirrors, Dinner

Toastmaster: Walter Beckjord, President, Cincinnati Gas and Electric Co.

Speaker: Professor Hubert N. Alyea, Princeton University

Subject: Atomic Energy: Weapon for Peace

Research Laboratory, Electro Metallurgical Co., Niagara Falls, N. Y.

Discussion by Arthur Gross, Metallurgist, Ohio Steel Foundry Co., Lima, Ohio

Discussion by C. W. Briggs, Technical & Research Director, Steel Founders' Society of America, Cleveland, Ohio

3. **Bull Session on Electro Furnace Operations**

Discussion leader, C. W. Briggs, Technical & Research Director, Steel Founders' Society of America, Cleveland, Ohio

2:00 to 5:00 pm—North Hall

MECHANICAL ASPECTS OF ELECTRIC FURNACE OPERATION

Chairman:

V. E. Zang, Vice-President, General Works Manager, Unitcast Corp., Toledo, Ohio

1. **Fume Control**

Preprinted paper by O. E. Erickson, Plant Metallurgist, Hanford Foundry Co., San Bernardino, Calif.

Discussion by C. A. Faist, Research Metallurgist, Burnside Steel Foundry Co., Chicago, Ill.

Discussion by E. Knaggs, Foundry Superintendent, Swedish Crucible Steel Co., Detroit, Mich.

2. **New Developments in Electric Arc Furnace Design and Operation**

Paper by W. B. Wallis, President, Pittsburgh Lectromelt Furnace Corp., Pittsburgh, Pa.

Paper by C. W. Vokac, Manager, Hydro-Arc Div., Whiting Corp., Harvey, Ill.

Paper by E. A. Hanff, Chief Engineer, Swindell-Dressler Corp., Pittsburgh, Pa.

3. **Continuation of Bull Session on Electric Furnace Operations**

Discussion leader, C. W. Briggs, Technical & Research Director, Steel Founders' Society of America, Cleveland, Ohio

9:30 am to 12:30 pm—Pavillon Caprice

MODERN HIGH POWERED ARC FURNACE

Chairmen:

C. F. Staley, Superintendent No. 2 Open Hearth Section, Armco Steel Corp., Middletown, Ohio

R. J. McCurdy, Melt Shop Superintendent, Republic Steel Corp., Chicago, Ill.

1. **Furnace Design, Maintenance and Operation**

Paper by G. D. Lawrence, Assistant Contracting Manager, Heroult Electric Furnace, American Bridge Div., U. S. Steel Corp., Pittsburgh, Pa.

Paper by Jack Atkinson, Melting Superintendent, Dominion Foundry & Steel Co., Hamilton, Ontario

Paper by Charles Hesselman, Assistant Masonry Superintendent, Newport Steel Corp., Newport, Ky.

Discussion by K. L. Grant, Superintendent, Los Angeles Electric Fce. Dept., Bethlehem Pacific Coast Steel Corp., Los Angeles, Cal.

Discussion by John Brown, Superintendent of Melting, Rotary Electric Steel Co., Detroit, Mich.

2. **Round vs. Oval Furnace**

Paper by J. Preston, Supervisory Trainee, Melt Shop, Timken Roller Bearing Co., Canton, Ohio

3. **Electric vs. Open Hearth Furnace**

Preprinted paper by C. F. Ramseyer, President, Ramseyer & Miller, Inc., New York, N. Y.

Discussion by H. W. McQuaid, Consulting Engineer, Cleveland, Ohio

Discussion by A. K. Blough, Superintendent Nos. 2 & 3 Melt Shop, Republic Steel Corp., Canton, Ohio

Discussion by James Sullivan, Turn Foreman, Open Hearth and Electric Furnace Dept., Republic Steel Corp., Chicago, Ill.

4. **Solidification of Steel in Ingot Molds**

Preprinted paper by L. H. Nelson, Superintendent Conservation and Quality Control, Republic Steel Corp., Chicago, Ill.

2:00 to 5:00 pm—Pavillon Caprice

METALLURGY

Chairmen:

D. L. Clark, Melting Superintendent, Simonds Saw & Steel Co., Lockport, N. Y.

G. Derge, Jones & Laughlin Professor of Metallurgy, Carnegie Institute of Technology, Pittsburgh, Pa.

1. **Nitrogen in Stainless Steels**

Paper by H. P. Rassbach, Metallurgical Engineer, Union Carbide & Carbon Corp., Chicago, Ill. and E. R. Saunders, Metallurgist, Technical Service & Development Laboratory, Electro Metallurgical Co., Niagara Falls, N. Y.

Discussion by D. J. Carney, Chief Development Metallurgist, South Works, U. S. Steel Corp., Chicago, Ill.

Discussion by D. G. Harris, Metallurgical Research, Republic Steel Corp., Canton, Ohio

Discussion by R. H. Henke, Manager of Quality Control, Allegheny Ludlum Steel Corp., Brackenridge, Pa.

Discussion by D. W. Murphy, Engineer, Research Dept., Bethlehem Steel Co., Bethlehem, Pa.

Discussion by E. Spire, Consulting Engineer, L'Air Liquide Society and R. Lee, Metallurgical Engineer, Canadian Liquid Air, Montreal, Canada.

2. **Sources of Inclusions from Pouring Refractories**

Paper by M. P. Fedock, Ceramic Engineer, Republic Steel Corp., Canton, Ohio

Discussion by J. G. Mravec, Melt Shop Metallurgist, Steel and Tube Div., Timken Roller Bearing Co., Canton, Ohio

Discussion by D. J. Carney, Chief Development Metallurgist, U. S. Steel Corp., Chicago, Ill.

3. **Sulphur Control in Electric Steelmaking**

Paper by B. R. Queneau, Chief Metallurgist, U. S. Steel Corp., Duquesne, Pa.

Discussion by H. W. Diefendorf, Metallurgist, Sanderson-Halcomb Works, Crucible Steel Co., Syracuse, N. Y.

Discussion by R. W. Shaw, Manager, Electric Furnace Shop, Allegheny-Ludlum Steel Corp., Brackenridge, Pa.

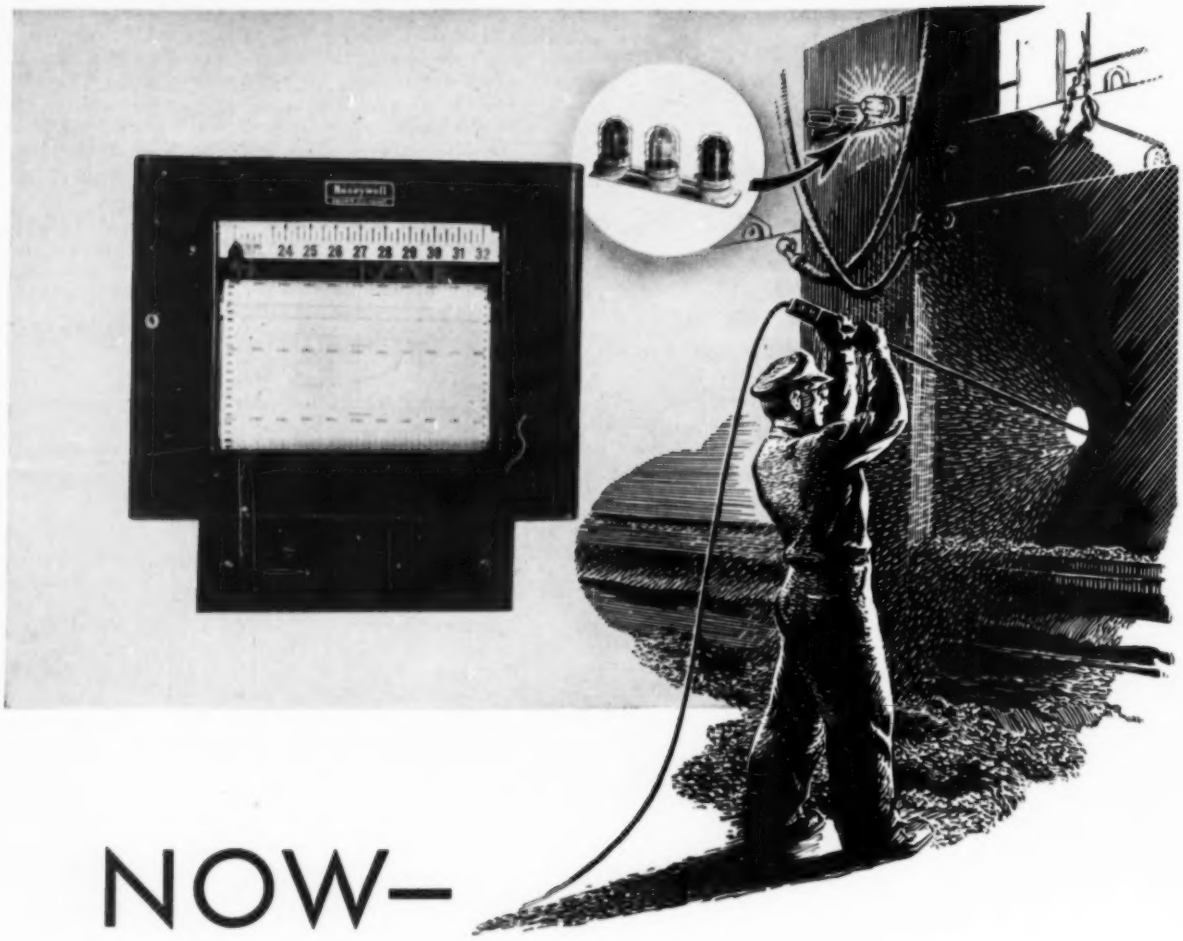
Discussion by Gilbert Soler, Assistant Technical Director, Universal-Cyclops Steel Corp., Bridgeville, Pa.

Discussion by F. E. Van Voris, Engineer, Research Dept., Bethlehem Steel Co., Bethlehem, Pa.

4. **Determination of McQuaid-Ehn Grain Size by Spectrochemical Analysis of Ladle Samples**

Preprinted paper by G. E. Ressler, Assistant Mill Metallurgist, Steel & Tube Div., Timken Roller Bearing Co., Canton, Ohio

Discussion by Gilbert Soler, Assistant Technical Director, Universal-Cyclops Steel Corp., Bridgeville, Pa.



NOW—

measure bath temperatures *this easier, better way*

New AUTOMATIC signalling features in the *ElectroniK* recorder bring greater simplicity and economy to the measurement of steel bath temperatures by the immersion thermocouple method. The instrument actuates remote color-coded lights near the furnace, to tell the operator when:

. . . thermocouple is properly connected and in operating condition.
. . . instrument is standardized and ready to record.
. . . thermocouple is preheated to correct temperatures.
. . . pen has recorded actual bath temperature.

The operator can make a complete measurement on signalled information alone . . . doesn't need to consult the *ElectroniK* recorder, which can be located remote from the furnace. Thermocouples last longer, because the operator leaves the element in the molten bath only long enough to get an accurate reading. This feature, in a typical installation, paid for the entire instrument cost in a single day.

The *ElectroniK* signalling recorder is equally applicable to measurements in the furnace or in the spoon. Our local engineering representative will be glad to discuss applications to your electric or open-hearth furnaces. Call him today . . . he is as near as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, 4573 Wayne Ave., Philadelphia 44, Pa.

● **REFERENCE DATA:** Write for Instrumentation Data Sheet No. 6.7-8a.

MINNEAPOLIS
Honeywell
BROWN INSTRUMENTS
First in Controls

Can the Electric Furnace

Compete with

the Open Hearth?

by C. F. Ramseyer

THE recent trend among nonintegrated steel companies to either install electric furnaces or to change over to them from open hearths, indicates the increasing acceptance by the industry of the superiority of the electric furnace for making steel from all cold scrap charges. While this trend is primarily because the electric furnace is fully competitive with the open hearth in melting cold charges, it is also because of the much lower capital cost of an electric furnace shop, as well as the fact that scrap is considerably cheaper than merchant pig iron.

As far as all cold scrap melting is concerned, there is no point in trying to make a formal camparison between a modern open hearth shop and a modern electric furnace shop, since no wholly new cold melt open hearth plants have been built in this country in recent years. Since the end of the war, on the other hand, ten or more, large, modern open hearth shops have been built to use hot metal.

Table I gives the breakdown of the capital cost of a one million ton per year electric furnace shop. The approximately $18 million cost is between 50 and 60 pct that of an equally modern open hearth plant; i.e. the complete cost of a comparable new million ton open hearth plant would run between 30 and 35 million dollars.

C. F. RAMSEYER is President of Ramseyer & Miller, Inc. in New York City. This article is an abstract of the paper presented at the AIME Electric Furnace Steel Conference, Cincinnati, Dec. 4, 1953.

Operating Costs Fixed Per Ton

The usual breakdown of items into which melt shop operating costs—the *Cost Above Net Metal*—are customarily divided provides a convenient method of comparing the two practices. Four items —fuel, fluxes, molds and stools, and ladle costs—are relatively constant per ton regardless of furnace output.

The outstanding difference between the two processes is the cost of fuel. The best electric furnace practice, assuming 8½ mills for power and 10 lb of electrodes, will average $6.00 or more per ton of ingots while open hearth fuel costs average $1.25 to $1.50 per ton.

There are a number of modern open hearth shops in the country, operating with 50 to 65 pct hot metal, which will consistently average 3 million Btu per ton of ingots. In contrast, there is at least one cold melt electric furnace shop producing plain low carbon steels whose power consumption dropped as low as 465 kwh per ton of ingots without the use of oxygen during one record month, and whose average power figure will not run more than 15 to 20 kwh higher than this. This is probably about the maximum extent to which power consumption can be reduced by good operating practice with existing

Table I. Capital Cost of Four-Furnace Electric Meltshop With One Million Ton Yearly Capacity

Buildings—complete with foundations	$ 2,526,150
Electric Furnaces—four 23-ft diam., complete with transformers, including foundations and refractories	$ 3,164,600
Cranes—4 scrap, 3 floor and 3 ladle, installed complete	$ 2,676,000
Charging Equipment—scrap buckets, scales, transfer cars, 7½-ton charging machine, plus charging boxes and buggies	$ 802,750
Pouring Equipment—iron and steel ladles, cinder pots and cars, hot metal transfer stations, ladle relining stand, ingot molds and cars	$ 1,093,500
Building and Operating Services (within building only) —water, sewer, lighting, railroad trackage, etc.	$ 425,000
Electrical Substation—main transformer, switchgear, circuit breakers, etc.	$ 1,716,000
Mold Preparation—building and platforms, complete with OET cranes, etc.	$ 425,200
Stripper—building, complete with two stripper cranes, etc.	$ 918,300
Fume Control—separate system for each furnace	$ 1,000,000
Miscellaneous—office, sanitary facilities, locomotives and rolling stock, auto trucks, oxygen plant, air compressors, magnets, lift trucks, dolomite slinger, storage facilities, etc.	$ 1,040,500
Total	$15,788,000
Engineering, Supervision, and Contingencies at 13 Pct	$ 2,052,000
Total Estimated Cost	$17,840,000

equipment. With larger, fast melting units tapping up to twice as much steel per heat, it should be possible to obtain a further reduction of 5 pct or more without too much trouble. In electric melting a 5 pct fuel saving is important because 5 pct of $6.00 is 30¢, or $300,000 per year for a million ton plant.

Ordinarily the amount of lime and limestone used in electric furnace practice is only a third to a half as much as that used in the open hearth. This is mainly because the electric furnace melts steel scrap, and steel scrap has already been refined. Most of the open hearths in this country, on the other hand, are used primarily to refine relatively impure pig iron.

Given the same charge composition, the electric furnace would probably show some slight saving in flux composition. Perhaps 10 pct, but nothing like the large difference between an all cold scrap electric furnace practice compared to high hot metal, flush-slag, open hearth practice. Such savings in flux requirements as the electric furnace might show would be due to the absence of any pick-up sulphur from the fuel, to shorter heat times with consequent less bottom and bank erosion, and to the fact that an electric, being a tilting furnace, could perhaps sometimes flush off part of its slag with a lower flux consumption than a stationary open hearth.

There would probably not be any significant difference between one practice and the other with regard to ladle costs and consumption of stools. The total cost of the principal operating production cost items would run between $8.00 and $8.50 per ton in the best current plain carbon steel electric furnace practice.

Operating Costs Fixed Per Furnace Hour

The rest of the customary meltshop operating *Cost Above Net Metal* item—i.e. labor and supervision, repairs and maintenance, and refractories—tend to remain more or less fixed per unit of time. A properly designed and operated electric furnace shop should show a lower cost for labor and supervision than an open hearth shop of similar capacity. From a study of relative force requirements, the difference should run between 35¢ and 50¢ a ton or more in favor of the electric furnace in equivalent modern million ton plants.

Repairs and maintenance also should be lower for the electric furnace, and does appear to be so on the basis of the limited information now available. This is primarily because of the smaller physical size of an electric furnace compared with an open hearth of the same capacity, as well as to the greater simplicity of electric furnace operation, i.e. the absence of uptakes, slag pockets, checker chambers, gas flues, waste heat boilers, etc. It should be possible to reduce repair and maintenance cost still further by more rugged design of both the mechanical and electrical parts of electric furnace equipment. Modern open hearth construction, on the other hand, is already so substantial that room for further improvement appears to be more limited.

The smaller size and far smaller amount of brickwork involved gives the electric furnace a considerable advantage with regard to refractory costs. There is, however, no reason to expect the remaining operating cost items to differ greatly between the two practices. These are such things as utilities (water, light, compressed air, etc.), yard switching, laboratory costs, tools and lubricants, slag disposal, etc. As a final item there must be included the meltshop's portion of the steel works over-all general plant expense. Since general plant expense is normally prorated on a labor basis—either cost or man-hr—the electric furnace should benefit slightly from its lower labor cost.

The *Cost Above Net Metal* of the newer, large size hot metal open hearth shops will range from slightly under $8.00 to over $10.00 per net ton of ingots. An average figure of $9.00 would be valid based on practice during the summer of 1953. In the case of the electric furnace it is doubtful whether any shop making plain carbon steel has been able to average much better than $13.50 or $14.00 per ton. Present day comparative costs, therefore, show that the modern hot metal open hearth has an average cost advantage of about $4.50 per ton over the best current all cold charge electric furnace practice. It must be remembered, however, that heat sizes in the case of electric furnaces are mostly under 100

Table II. Assumed Future Electric Furnace Heat Times

Data	Furnace Sizes 16 to 20 Ft	Furnace Sizes 21 to 25 Ft
A—Make-up of total heat time, tap-to-tap		
1—Charging		
Three buckets, on the average	15 min	—
Three buckets + some door-charged boxes	—	20 min
2—Melting, range of calculated values	1:59 to 2:13	2:08 to 2:22
3—Refining	30 min	35 min
4—Fettling	25 min	25 min
5—Delays	25 min	25 min
Total heat times, tap-to-tap	3:34 to 3:48	3:53 to 4:07
B—Transformer utilization (capacity) factor during meltdown[1]	85 pct	80 pct
C—Average furnace radiation and convection losses (in kwh/hr) during meltdown	1000 to 1500	1650 to 2300
D—Average electrical losses during meltdown period	6.5 pct	6.5 pct
E—Average power factor during meltdown	80 pct	80 pct
F—Kwh equivalent to heat content (above 60°F) of one net ton of steel (plus 5 pct of slag) at 3000°F less exothermic reactions	355 kwh	355 kwh
G—Ratio of OK ingots to molten steel in the bath (equals 100 − pct—pct of pit scrap and butts)	97.5 pct	97.5 pct

[1] The meltdown period is arbitrarily taken as the time required to melt all the scrap and flux charged and to raise the metal and slag to 3000°F.

tons compared with an average of over 250 tons per heat for the newer post-war open hearths.

Total Heat Time Comparison

The sum of the charging, melting, refining, fettling, and delay times is the total heat time, tap-to-tap. Dividing the average tons of ingots per heat by the average total heat time gives the average production rate in tons per hr. Electric furnace heat times run from 2 hr on small furnaces to 7 to 8 hr on some of the larger, underpowered door-charge units. Heat times in the best shops will run from 3½ to 5½ hr on single slag practice, plain carbon steel heats. This compares to the 10 to 11 hr required for open hearth operation.

Existing well run electric furnace shops, tapping from 80 to 130 ton heats, have outputs ranging from 16 to 25 or more tons per furnace hr. The newer, large, hot metal open hearths will average from 21 to 24 tons per hr or more. Some of the latter shops are so new that they have not yet had time to develop their full potentialities. The feasibility of building open hearths with capacities larger than 300 tons per heat for ordinary hot metal plus scrap practice is rather questionable because of the disproportionately rapid increase in the cost of buildings and cranes.

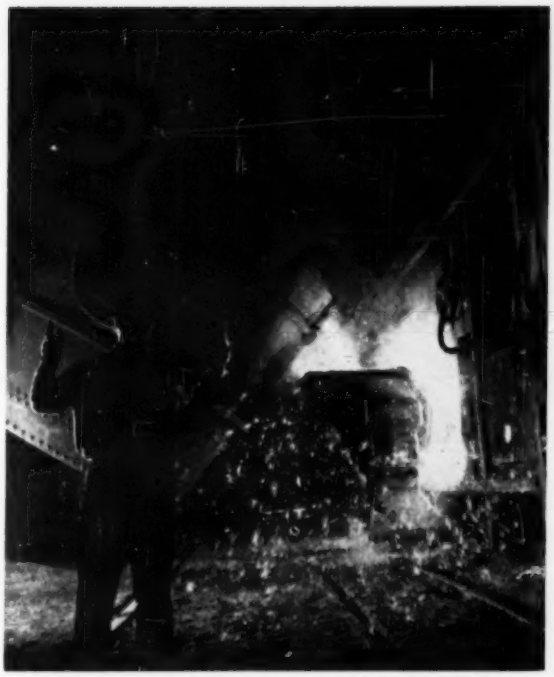
The only way that the electric furnace can hope to compete with open hearth operations of this order of magnitude is to go to larger units with still higher transformer capacities, i.e. 23 to 25 ft furnaces with 40,000 to 50,000 kva transformers. Since no actual experience with such larger units exists, any consideration of their possibilities must be on a speculative rather than on a factual basis.

Future Possibilities

As already indicated, open hearth practice—now some 75 years old—would appear to be close to the peak of its development. This is, of course, a somewhat dangerous statement to make as things sometimes happen that enable an old process to take on a new lease of life. Nevertheless, it begins to look as if the limit in size of open hearth furnaces has been reached at 300 tons per heat. It also would seem rather optimistic to expect a large 300 ton open hearth shop to average less than 10 hr per heat, tap-to-tap, or 30 tons per hr.

The making of plain carbon steels in large, modern, highpowered electric furnaces, on the other hand, is a relatively recent development. It is not unreasonable, therefore, to expect it to show considerable further improvement. If no great change in the relative prices of fuel oil, electrodes, and electric power is assumed for the immediate future, the possibility of comparing the operating costs of the two practices narrows down to a study of whether or not the production rate of the electric furnace can be raised sufficiently to offset a major part of the open hearth ingot-ton cost differential.

Since for a given size heat the reciprocal of production rate is tap-to-tap heat time, a good way of arriving at electric furnace production rate possibilities would seem to be in establishing what might be expected in future electric furnace heat times. To estimate this, reasonable, definite figures for the five periods into which heat time is divided—charging, melting, refining, fettling, and delays—must be assumed. The assumed values taken for these are shown in Table II.



Supreme in its ability to convert high hot metal charges into plain carbon steel, the open hearth produces approximately 85 pct of the country's steel.

The relatively high thermal efficiency of an electric furnace, makes an over-all heat balance during meltdown a rather simple thing. Such a heat balance can readily be set up in the form of an equation as follows:

$$\left[335 \text{ kwh per ton} \times \frac{\text{heat size}}{100 \text{ pct} - \text{pct (pit scrap and butts)}} \right] +$$

$$\left[\begin{matrix} \text{furnace radiation loss} \times \text{meltdown hr} \\ \text{(in kwh per hr)} \end{matrix} \right] \div \begin{matrix} \text{average power factor} \times \\ \text{(during meltdown)} \end{matrix}$$

$$\begin{matrix} \text{electrical efficiency} \\ \text{(during meltdown)} \end{matrix} = \begin{matrix} \text{transformer capacity} \times \\ \text{(in kva)} \end{matrix}$$

$$\text{transformer utilization factor, pct} \times \text{meltdown hr}$$

The sum of the first two items equals the amount of energy required to melt the charge and provide for radiation losses. This value is divided by the product of the next two items to convert the sum to kva and to take care of electrical losses. The cal-

Table III. Furnace Diameters and Heat Sizes with Assumed Transformer Capacities

Furnace Diam, Ft	Ingots Per Heat, Net Tons	Transformer Capacity	
		Per Furnace, Kva	Per Ton of Ingots, Kva
16	50	16,000	320
17	60	18,000	300
18	70	20,000	286
19	85	25,000	294
20	100	30,000	300
21	115	35,000	304
22	130	40,000	308
23	150	45,000	300
24	160	45,000	281
25	180	50,000	278

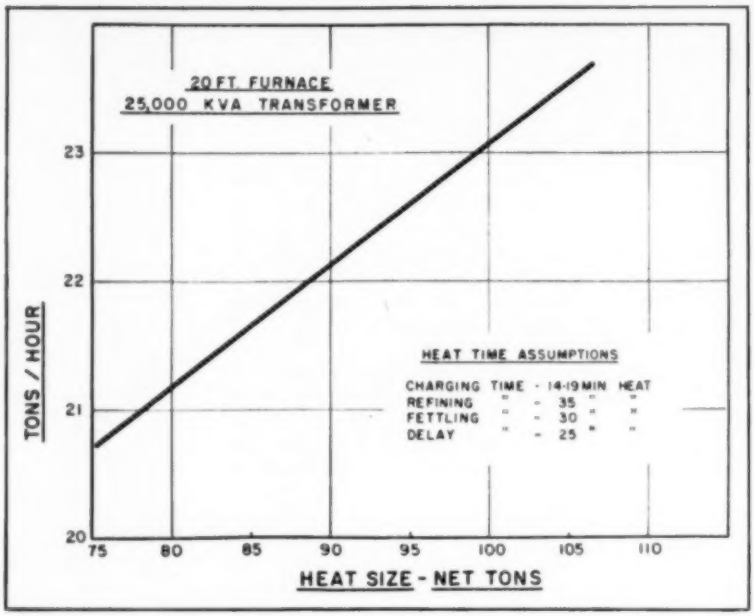


Fig. 1—Graph shows the calculated variation of tons per hour with tons per heat for a 20-ft electric furnace with a 25,000 kva transformer. The assumed meltdown transformer utilization factor is 85 pct.

culated value in kva hr on the left hand side of the equation is then equal to the transformer capacity, multiplied by a transformer utilization factor and the meltdown time in hours.

The values used for the heat and transformer capacities of various size furnaces are shown in Table III. The transformer sizes used are based on approximately 300 kva per ton of ingots taken to the nearest round figure for transformer capacity. The sizes agree with actual present practice only in the case of the three smaller furnaces, i.e. the 16, 17, and 18 ft diam ones. There is actually one 20,000 kva transformer on a 16 ft furnace, but electrical units larger than 20,000 are not currently in use on any furnace smaller than 20 ft. A few new 20 ft top charge units have 25,000 kva transformers, and these are also 22 ft units with nominal 25,000 kva transformers. Nominal, because their actual capacities on the customary 55°C rise basis are equivalent to about 34,000 kva. All the transformer capacities shown for units of from 19 to 22 ft are, therefore, somewhat larger than present practice because approximately 300 kva of transformer capacity was provided for each ton of ingot capacity. The same is true of the 40,000 to 50,000 kva transformers shown for the 22 to 25 ft furnaces; these are much larger than anything now in use.

Table IV. Calculated Theoretical Production Rates With Annual Capacities of Four-Furnace Shops

Furnace Diam, Ft	Production Rate Per Gross Furnace Hr, Net Tons	Annual Ingot Capacity, Net Tons[1]
16	14.0	475,000
17	16.2	550,000
18	18.4	625,000
19	22.9	780,000
20	27.4	930,000
21	29.3	1,000,000
22	33.5	1,140,000
23	38.2	1,300,000
24	39.0	1,325,000
25	43.7	1,500,000

[1] A 97 pct availability is assumed for the four furnaces.

It is well known that steelmakers generally try to charge as big heats as they can. Fig. 1 shows the reason for this—more tons per hr. The curve is based on tons per hr values calculated for a 20 ft furnace with a 25,000 kva transformer with the help of the meltdown period heat balance equation plus the indicated charging, refining, fettling, and delay time assumptions. The range covered, 75 to 105 ton heats, corresponds to the actual range in the size of heats tapped from 20 ft furnaces in this country. The curve indicates that a 13 pct increase in tons per hr should be obtainable from a 20 ft unit with a 25,000 kva transformer merely by increasing the size of heats from 75 tons up to 105 tons.

Fig. 2, for a 20 ft furnace tapping 100 net tons heats, shows the effect of increased transformer size on output. It carries the present range of transformer size installed on 20 ft shells of from 12,000 to 25,000 kva on up to 35,000. In making the calculations for Fig. 2, it was assumed that the meltdown transformer utilization factor would vary linearly from 92 pct on the smallest kva unit down to 76.5 pct on the large kva size. These are purely arbitrary values based on assuming 90 pct for a 15,000 kva unit and 80 pct for a 30,000 kva one.

By use of the heat balance equation plus the values given in Table II, the production rates shown in Table IV were calculated for different size furnaces. The capacity figures in Table IV are based primarily on known performance data as to transformer utilization, power factor, and radiation losses, plus charging, refining, fettling, and delay times actually obtained in regular practice in either electric furnace or open hearth shops. The figures indicate that it should be possible to produce a million tons of steel per year from four 21-ft furnaces, powered with 35,000 kva transformers, and a million and a half tons per year in four 25-ft furnaces, powered with 50,000 kva transformers.

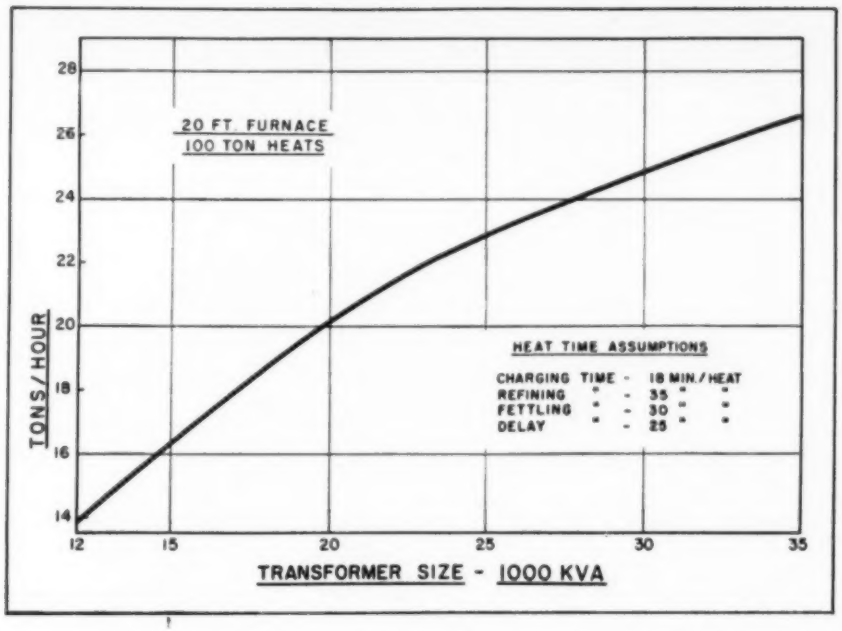


Fig. 2—The theoretical effect on the output of a 20-ft electric furnace tapping 100 ton heats is shown when the transformer size is increased. The meltdown transformer utilization factor is assumed to vary from 92 to 76.5 pct.

Since the number of large, modern electric furnace shops making plain carbon steels is extremely limited, the operating cost data available for comparison with the open hearth is very meager. However, Table V gives an estimate as to the magnitude of the current average fixed *Cost Above Net Metal* for various sized furnaces. The four cost items which are relatively constant per ton of ingots—fuel, fluxes, molds and stools, and ladle expense—are all omitted from these hourly cost figures.

The difference between the calculated *Cost Above Net Metal* per ton of the largest, and consequently the lowest cost, electric meltshop in Table V, and the average $9.00 *Cost Above Net Metal* for the latest large, modern hot metal open hearth shops, is $1.50 per ton instead of the present difference of $4.00 to $4.50 per ton. A dollar and a half is just about the difference between the fixed charges on the capital investment required in the one case compared to the other. That is, it is equal to 10 to 12 pct for fixed charges on the difference between $18.00 per annual ton of electric furnace capacity *vs* $30.00 to $35.00 per annual ton for the open hearth. There is, then, a good possibility that an all cold scrap electric furnace plant could compete with a hot metal open hearth in over-all operating cost, depreciation included, by using large enough furnaces.

Table V. Calculated Hypothetical Operating Cost Above Net Metal

Furnace Diam, Ft	Total Cost[1] Per Gross Operating Hr, $	Gross Furnace Hr Tons	Total Cost[2] Per Net Ton Ingots, $
16	80.00	14.0	13.71
17	83.00	16.2	13.12
18	86.50	18.4	12.70
19	90.00	22.9	11.93
20	93.00	27.4	11.39
21	97.50	29.3	11.33
22	100.00	33.5	10.99
23	103.00	38.2	10.70
24	107.00	39.0	10.74
25	110.00	43.7	10.52

[1] This covers all items which are relatively constant per ton rather than per unit time, including general plant expense—but excludes the cost of fuel (power plus electrodes), molds, fluxes, and ladle expense.

[2] The figures are derived by dividing the figures of the second column by the tons per hour figures of the third, and then adding $8.00 per ton; i.e., $6.00 for fuel (melting power plus electrodes) and $2.00 to cover molds and stools, fluxes and ladle costs.

Hot Metal Use

At the present time experience in the electric furnace use of hot metal is limited. Such experience as there is indicates that a door-charge electric furnace can use up to 40 pct hot metal and a top charge unit up to 25 pct hot metal without loss of output as measured by tons per hour. Any increase beyond these percentages with conventional practice tends to prolong the heat because of the added time required to eliminate carbon and carry out the other refining reactions.

From the thermal point of view, a 65 pct hot metal electric furnace charge actually requires considerably more heat units per ton of ingots than an all cold scrap charge. This results from the heat requirement of the endothermic refining reaction between the carbon in the pig iron and the iron oxide of the ore. In addition, the higher slag volume plus the extra sensible heat lost due to the greater volume of reaction gases increase the total heat requirement by approximately 150 kwh per ton compared to an all cold scrap charge. The actual electric power requirement, however, will be slightly lower because of the sensible heat input of the liquid metal which is equivalent to approximately 200 kwh. There is, therefore, little or no net over-all saving of electrical energy in hot metal plus ore practice.

Regardless of the speed with which it may become possible to refine hot metal in electric furnace practice, heat balance figures show that the over-all fuel saving, i.e. the combined reduction in power and electrode cost in hot metal, plus ore practice, will be very limited. Since some 85 pct of the country's steel is currently made by hot metal and scrap practice—practically all of it in the open hearth—it is obvious that the electric furnace can never become a really important factor in the steel industry until it has proved its ability to handle hot metal economically.

McQuaid-Ehn Grain Size Determined By Spectrochemical Analysis

by G. E. Ressler

AUSTENITIC grain size is controlled primarily by the addition of aluminum under proper slag and molten metal conditions. The Timken Roller Bearing Co. has found that a range of 0.015 to 0.035 pct metallic aluminum produces a fine-grained killed steel in the carburizing and medium carbon grades.

Wet chemical methods for aluminum determinations have been useful for some time in standardizing melting practices to achieve grain size control. However, when the analysis of a large number of heats is necessary, wet chemical determinations are not practical because of the cost and time required. With the advent of the spectrochemical method of obtaining chemical analysis and the subsequent development of the direct reading spectrometer, it is now economical to make numerous aluminum determinations.

Correlated Data

The spectrochemical method reports the metallic aluminum together with the aluminum present as an oxide. Numerous wet chemical determinations have shown that the Al_2O_3 content runs consistently between 0.006 to 0.010 pct in the fine-grained aluminum steels. This percentage of Al_2O_3 represents 0.003 to 0.005 pct aluminum present as an oxide. Since this amount of the aluminum is in the oxide form it is not effective in controlling grain size.

Timken's experience has shown that when 0.015 pct minimum spectrochemical aluminum is retained with standard addition and deoxidation practice, the aluminum present as an oxide is a constant factor of 0.003 to 0.005 pct. The factor of 0.003 to 0.005 pct can thus be used in correcting the spectrochemical results to effective metallic aluminum content. If an excessive amount of Al_2O_3 is formed because of improper furnace conditions, the expected aluminum recovery either as an oxide or in the desired metallic form is not obtained.

G. E. RESSLER is Assistant Mill Metallurgist, Steel & Tube Div., Timken Roller Bearing Co., Canton, Ohio. This article is an abstract of the paper presented at the AIME Electric Furnace Steel Conference, Cincinnati, Dec. 2-4, 1953.

Late in 1949, spectrochemical aluminum analysis were run on both early and late ladle tests. The first extensive study included 961 electric furnace heats of TS 4720 steel and other higher alloy grades of carburizing steels melted for the Timken roller bearing factory. The relationship between spectrochemical aluminum determinations and McQuaid-Ehn grain size is shown in Table I. This data points up the following:

A—All 881 heats finished 0.016 pct aluminum or higher, and 879, or 99.8 pct, are No. 6 gr size or finer while all 881 heats are No. 5 gr size or finer.

B—In the aluminum range 0.011 to 0.015 pct, the grain size still remains fine with a trend to the coarser side of the fine-grain range.

C—In the aluminum range 0.006 to 0.010 pct, the grain coarsening is pronounced at 1700°F.

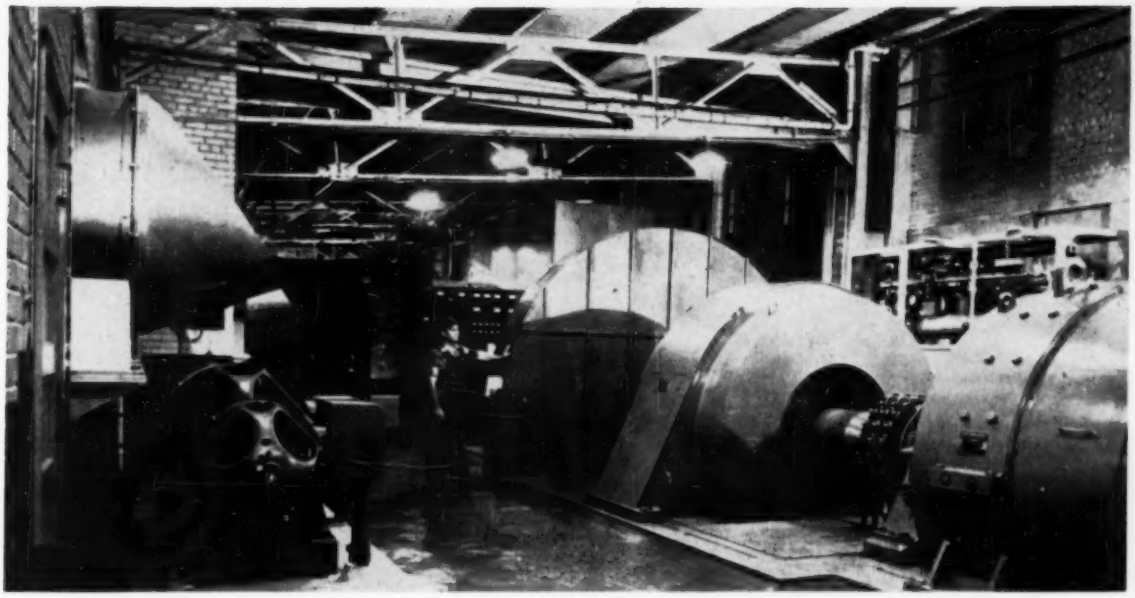
D—In the aluminum range 0.000 to 0.005 pct, all the heats coarsen at 1700°F.

On the basis of this convincing evidence, that fine-grained steel is assured by a minimum of 0.016 pct spectrochemical aluminum content, the Timken roller bearing factory consented to accept spectrochemical determinations as the yardstick for measuring grain size in its steel. At present, in the roller bearing factory grades, micro-inspection on carburized tests are made only when the aluminum content is outside the recommended aluminum content range. However, additional data on heats with 0.012 to 0.016 pct aluminum has shown that in type TS 4720 steel coarse grain steel does not occur down to 0.012 pct aluminum.

Early in 1953, spectrochemical aluminum determinations on over 2000 heats had been acculmulated with continued verification of previous results. A number of Timken customers were approached on using spectrochemical aluminum determinations for the release of fine-grained steels. As a consequence fine-grained steels are now released to Timken customers on the basis of spectrochemical aluminum analysis with satisfactory results.

Table I. Relationship of Spectrochemical Aluminum to McQuaid-Ehn Grain Size

	Fine Grain Size						Coarse Grain Size		
McQuaid-Ehn grain size	8	7/8	6/8	6/7	5/8	5/7	4/7	3/7	3/6
Number of heats	537	277	133	5	2	1	2	1	3
Aluminum, Pct	Percentage of Heats								
0.000-0.005	—	—	—	—	—	—	—	—	66.7
0.006-0.010	0.2	0.7	4.5	20.0	—	100.0	100.0	100.0	33.3
0.011-0.015	2.8	7.6	18.0	40.0	—	—	—	—	—
0.016-0.035	83.6	75.1	64.0	40.0	100.0	—	—	—	—
0.036-0.040	8.4	8.3	8.3	—	—	—	—	—	—
0.041-0.045	3.2	3.6	2.3	—	—	—	—	—	—
0.046-0.060	1.8	4.7	2.9	—	—	—	—	—	—



Motor room of the CF&I 25-in. structural mill showing the slip regulator at right behind the flywheel set. The 4000-hp mill motor and control are in the background.

Reconstruction of CF&I Mill Increases Capacity and Flexibility

by William Brill and R. H. Wright

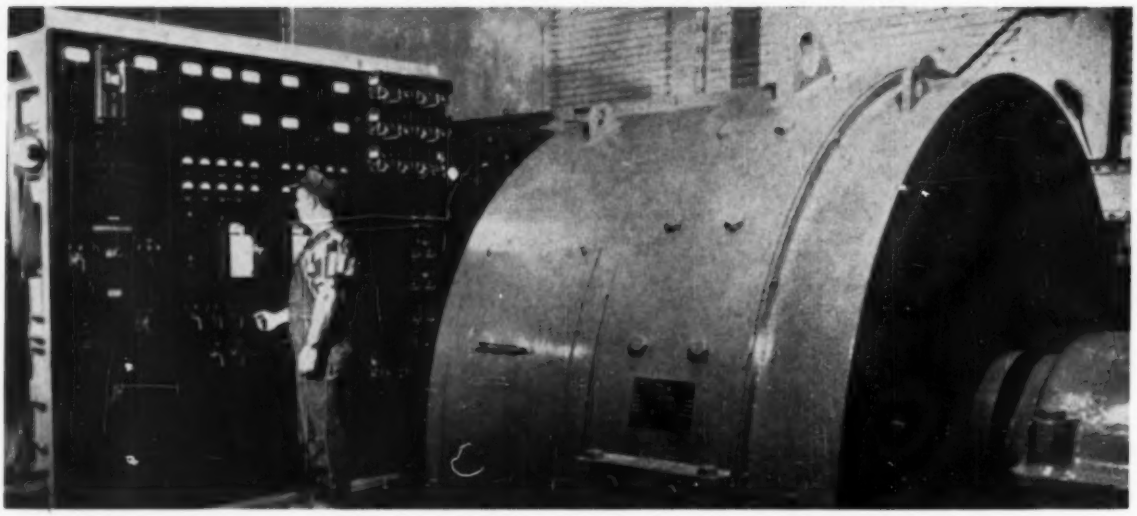
THE expanding western market for steel products required the Colorado Fuel & Iron Corp. to make extensive additions to the Pueblo plant. The first step in the expansion program was the installation of a new 15,000 kw turbogenerator to provide additional power and to secure maximum utilization of available waste fuel. This increased the total generating capacity of the plant to 45,000 kw.

The new seamless tube mill, now in operation, makes the chief demand on the augmented capacity of the power system. The tube mill also requires several sizes of round billets that previously had not been rolled in the Pueblo plant. To provide for this increased requirement for semi-finished steel, extensive improvements were made at the 25-in. structural mill.

The structural mill has two three-high stands and one two-high stand and the usual arrangement of traveling tilting tables. Previously this mill had rolled standard structural shapes, track fastenings and flats. Blooms were reheated in two small furnaces of limited capacity. These furnaces have been replaced by two completely new and modern furnaces of more than twice the original capacity. The tables on the entry side of the mill were rebuilt to accommodate this change. Other changes included a new scale disposal system, a new current collector system for the traveling tables and a new 4000 hp dc motor for the main drive with flywheel motor-generator, slip regulator, switchgear, and control.

Since the new 4000 hp mill motor had to be located in the space occupied by the old drive, it was necessary to shut the mill down to make the changeover. The continuous demand for tie-plate and structural shapes made it necessary to keep the down time to a minimum. By following a carefully worked out plan the construction crews were able to have the mill back in regular production in 21 days. This is a remarkable record because much of the construction work could be done only after the mill was shut down. Because of the compact layout only one new furnace and the flywheel motor-generator could be set in place before the mill was shut down. During the 21 day shutdown period, the two old furnaces were removed and the scheduled mechanical changes to the mill were completed. The old mill drive was removed, the new 4000 hp

WILLIAM BRILL is Director of Engineering, Colorado Fuel & Iron Corp., Pueblo, Colo. R. H. WRIGHT is associated with Westinghouse Electric Corp., East Pittsburgh, Pa.



Control panels for mill drive includes an 8-point master switch. One of the 1750-kw generators on the flywheel set is in the foreground.

motor with completely new foundation and ventilating system was installed, all electrical equipment was wired and tried out, and construction work was started on the second new furnace.

The mill was driven originally at 75 rpm, constant speed, by a 3000 hp, 6600 v wound rotor induction motor. The motor drove the mill through a reduction gear unit having flywheels on the pinion shaft. A magnetic secondary control panel with permanent slip resistance was used to start the motor and to equalize the peak loads. On some sections, the steel would not enter certain passes at the normal mill operating speed. It then became necessary to plug the motor to bring the speed down to a point where the metal would enter. Then when the mill was reaccelerated the motor had to carry not only the rolling load but also the acceleration load of the flywheel. This type of operation plus normal mill jogging imposed severe duty on the 6600 v switchgear.

The principal shortcomings of the old constant speed drive for rolling structural shapes were the lack of flexibility and the limited tonnage capacity. Many sections could be rolled at speeds above 75 rpm and considerable time could be saved if the speed could be reduced momentarily to enter difficult sections or to prevent cobbles. The original drive was entirely unsatisfactory for rolling large round billets because these are best rolled two-high reversing. For these reasons the old constant speed drive was replaced by a dc drive with reversing control.

The new mill motor is rated at 4000 hp, 75/175 rpm, 700 v and is direct connected to the mill pinion stand. The motor is supplied from a 514 rpm, four-unit flywheel motor-generator consisting of two 1750 kw dc generators, a 4000 hp 6600 v wound rotor induction motor and a 70,000 lb steel plate flywheel 13 ft in diam.

The main machines have enclosing covers for down-draft ventilation. Because of the scarcity of suitable cooling water a non-recirculating type air system is used. Filtered air in quantity equal to the total requirements of all the machines plus an allowance for leakage is forced into the motor room by six propeller type fans. Exhaust fans in the basement draw air through the machines and discharge it outside. One-third of the fresh air is drawn through a humidifier to reduce the temperature. Because of the low humidity in the Pueblo area the humidifier is quite effective in reducing the temperature of the motor room. In addition, the moisture which is added to the air improves the operation of brushes and commutators. The volume of air handled is 20 pct above normal to compensate for the altitude.

The 6600 v power is supplied to the flywheel motor-generator from a new metalclad switchgear structure. One of the air circuit breakers in this structure is for the dynamic braking circuit of the flywheel set. A liquid slip regulator in the secondary circuit of the induction motor regulates the ac input during starting, running, and dynamic braking. Motor room auxiliaries are supplied from a 220 v control center which is fed from a transformer located outside the building. The control center includes current limiting reactors in the incoming lines.

The exciters and dc control for the mill drive are designed for standard reversing service. The operator's control is located on the bridge on the entry side of the mill and includes an instrument panel, an 8-point master switch, and a foot switch for control of the mill drive. When the mill is rolling structural shapes the 4000 hp motor runs continuously in one direction and the normal speed is determined by the position of the master switch. If it becomes necessary to reduce the speed momentarily for any reason, the foot switch is depressed and the speed drops quickly to a preset value. Normal speed is resumed as soon as the foot switch is released. For reversing service the motor is controlled entirely by the hand master switch.

The nature of the load on this mill is such that dc power could have been obtained either from a synchronous motor-generator or from a flywheel set. However, it was considered desirable to keep the line peaks down to a minimum so a flywheel set was used. With a synchronous set sustained peaks of over 8000 kw and transient oscillations of over 15,000 kw were possible. With the flywheel set the maximum peaks on the 6600 v line have been limited by the liquid slip regulator to 3500 kw.

Electric Steel Foundries Control Dust Emissions in Los Angeles Area

Mandatory dust control in the Los Angeles area promoted the use of various types of dust collectors. The tube-type bag filter using Orlon bags has been the most successful. At last report this type of dust collector had been in operation for seven months and had not required any maintenance or manual cleaning during that time.

by O. E. Erickson

SHORTLY after the Los Angeles air pollution control district was formed in 1948, the electric steel foundries were notified that uncontrolled dust emissions into the atmosphere must be eliminated. The first attempts to control this dust was to use the dust collecting equipment already in use in the foundries. This equipment consisted of various wet collectors and bag collectors which are standard for foundry shake out operations.

Properties of Furnace Dust

The analysis of furnace dust changes drastically during the progress of a heat. During the meltdown period, the Fe_2O_3 content of the dust runs approximately 40 pct by weight. Once the scrap is completely melted, the Fe_2O_3 content of the dust drops to well below 20 pct. The balance of the dust is made up of oxides of silicon, calcium, phosphorus, manganese, and sulphur. Also present is the dust from furnace additions such as chromium, vanadium, tungsten, molybdenum, and aluminum. At the present time the dust recovered is not of sufficient value to offset the cost of collection, even on a long term basis.

The size analysis of a typical electric furnace dust sample is given in Table I. Not only is the dust very fine, but it also has a high angle of repose and tends to adhere to filter fabrics, both cotton and synthetic.

O. E. ERICKSON is Plant Metallurgist, Hanford Foundry Co., San Bernardino, Calif. This paper was presented at the AIME Electric Furnace Steel Conference, Cincinnati, Dec. 4, 1953.

The dust loading that can be expected from electric furnaces varies considerably as to concentration during the various stages of the melting process. One operator, who runs two 6-ton furnaces, collects approximately three tons of dust every 24 hr. He handles 40,000 cfm in his collecting system, which gives an average dust loading of 0.7 grain per cu ft of air handled.

Wet Collectors

Considerable time and money was spent on various types of wet collectors during the early days of emission control. It was soon found, however, that the wet collectors were unable to handle dust particles less than five microns in size. This was entirely inadequate, as shown by the particle size analysis in Table I. It was found that if the water stream was to be effective in the collection of dust particles, the water particle size must be the same size as the dust particle. In the devices tried, it was not possible to achieve water particle sizes small enough for good dust collection.

The air stream from electric furnaces also contains some sulphur compounds. When these compounds were taken through the water stream of the wet collector various sulphur acids were formed which caused corrosion in the equipment unless stainless steels were used.

In these systems the fan is placed on the upstream side of the dust collector. The fan, therefore, is required to handle a large amount of dust laden air plus a considerable amount of water vapor carried over from the spray system. The dust and spray

Table I. Electric Furnace Dust Particle Size

Size in Microns	Pct
0 to 5	67.9
5 to 10	6.8
10 to 20	9.8
20 to 44	9.0
44 and over	6.5

combined caused extremely high fan maintenance. One electric furnace operator reported that the fan on his equipment required repair and balancing every week.

Baghouse Collectors

Some operators who had flat bag dust collectors in use in the foundries attempted this method for dust collection. The temperature of the air stream to the dust filters is controlled by the addition of atmospheric air or by running a wet collector ahead of the baghouse. Despite the high collection efficiency of these bag filters they did not prove successful. As stated before, the dust has a high angle of repose and tends to adhere to fabrics. Consequently the agglomerating quality of this dust makes shaking the bags very difficult. When shaking periods are extended in an attempt to clean the cloth the bag wear becomes excessive.

When these operational difficulties became apparent one manufacturer developed a tube-type dust filter using Fiberglas bags. The theory underlying this construction was that the Fiberglas could withstand the direct air stream temperature from the electric furnace. Although a number of these units are still in operation, they also are not completely efficient. The Fiberglas bags are extremely fragile and must be shaken by hand. Because of the care which must be used in shaking to prevent damage to the bags, they are impossible to clean thoroughly. The problem of dirty bags is further complicated when foundry operations are shut down. The moisture in the air stream condenses in the dirty bags making them even harder to handle than when operating at elevated temperatures.

Electrostatic Precipitators

Electrostatic precipitators are also being used for the collection of emissions. This equipment was designed to take the air stream directly from the furnace without cooling. When placed in operation, the equipment did not meet the specifications or the requirements of the air pollution control district. From the analysis of the dust given earlier, it is apparent that a majority of the particles are inert. It is, therefore, impossible for the electrostatic precipitator to put a sufficient charge on the particles to make them stick to the collecting devices in the filter and prevent them from passing on through to the atmosphere. This is particularly true of the air stream from the electric furnaces because of the high molecular activity of the particles at that high temperature.

To achieve satisfactory results with electrostatic precipitators, it has been necessary to install an extensive water cooling system ahead of the precipitator to cool the air stream and wet the dust particles. When wet the dust particles are sufficiently ionized and collection efficiency is substantially improved. Of course, the problems connected with the wet system described before are now added to the installation. Also, the initial cost and the operating cost of an electrostatic precipitator are a good deal higher than those of any other dust collector.

Tube-Type Orlon Bag Filter

The most successful system thus far has been a tube-type bag filter using Orlon bags and combining an adequate reverse air flow with mechanical shaking. This equipment has passed the most exacting tests by the Los Angeles air pollution control district, and the foundry operator using this type of collector has been given an unconditional permit by the district.

A hood arrangement at the furnace has been especially designed to provide large openings, so that large amounts of air will be drawn into the system at the points of highest temperature. This tempers the air stream temperature and prevents warpage of hoods around the electrodes. The hooding system is limited by the size of the furnace and the design for charging.

The system is designed for an air temperature of 180°F at the point of entry into the dust filter. This temperature is attained without the addition of auxiliary air by moving large quantities of air through the hoods. However, an inlet duct is provided in the system for the addition of atmospheric air should the air stream temperature exceed a 190°F level. The inlet normally is closed, but a damper automatically controlled by a temperature regulating device will open if the temperature exceeds the predetermined level.

The dust filter itself is a four section continuous automatic unit. Each section receives a cleaning every hour, and one section is shaken every 15 min. During the shaking period the section is automatically cut off from the main fan suction and shaking is supplemented with reverse air. The shaking period is carefully controlled to prevent the removal of the dust precoat on the filter bags. The precoat is necessary for successful operation because a majority of the dust particles are smaller in size than the pores or openings in the cloth.

This dust filter requires no operator and is so arranged that the collected dust can be removed from the filter while the unit is in operation. This type of dust collecting unit can be used for air temperatures up to 250°F. The control of the air temperature can be accomplished in several ways. Atmospheric air can be added to the air stream or water vapor can be added to the dust laden stream to reduce the temperature. Water can be added to the air stream without danger of condensation in the dust filter as long as the dew point remains well below 250°F. An air to air heat exchanger can also be used. These are design considerations which must be considered for each individual application.

From the operating results obtained in attempting to meet the requirements of the Los Angeles air pollution control district, it appears that the tube-type dust collector using Orlon bags and designed with proper shaking and control devices is the best solution of the problem, considering both the initial cost and operating cost of the dust collection equipment.

Acknowledgment

The author wishes to express appreciation to the Horrel Co. mechanical engineers whose efforts made this paper possible.

Review of Russian Practice Reveals Rail Steel Production Methods

by Carl A. Zapffe

SINCE the time of World War I, *flakes* have been recognized as a principal problem in the production of low alloy and medium or high carbon steel forgings. U. S. industries are still suffering important losses both from occurrence of flakes and from expensive measures used to avoid them. In Russia the study of flakes was assigned special priority by Government order about the time of their involvement in war with Germany.

At a special seminar, apparently held in 1950 at the A. A. Baikov Metallurgical Institute under the auspices of the Soviet Academy of Science, a score of authors presented fifteen papers which comprise the chapters of the current book: *The Heat Treatment of Rails.* Both research and industry were represented. Bardin, the editor of the collection, pointed out in his introduction that improving the quality of rail steel was designated for special study by the Stalin Five-Year Plan for railways in the USSR, and that, historically, Russia's greatest metallurgists had worked on the general problem: Chernov, Baikov, Baboshin, and others.

The first rails in Russia were made of puddling iron in the middle of the last century. A Russian "first" (!) is claimed for 1864 when heat treatment was applied in a Lower Saldinski factory, the mechanical properties being found considerably improved by rapid cooling after hot-working. Subsequent developments had to do with defining optimum profiles, weights, and composition. Experimentation with alloys containing Cr, Ni, Mo, V, etc., ended with C-Mn compositions more or less similar to those in use in other countries with exceptions to be noted later. It was then found that the rails were subject to flaking; and for the past quarter century or more the correction of this defect has been a specific study. Among early heat treating procedures designed to alleviate the problem, Grum-Grzhimailo in 1926 instituted a hardening and tempering schedule at the Permski works; and Shadrin in 1927 introduced a sorbitizing treatment at Serovski.

Then it was discovered that hydrogen was fundamentally involved in flaking. Programs were organized in which research institutes cooperated with rail mills. In 1941 Russia went to a *heavy profile* rail of 50 kg per m, and later to one of 65 kg (101 and 131 lb per yard, respectively). These heavier gages aggravated the flake problem, and in that same year there was an All-Soviet Conference on Flakes in Steel. Much further work was conducted throughout the war and postwar period, this being the subject of the 1950 Rail Seminar.

Russian Flake Theory

Apparently between 1939 and 1941 the hydrogen theory for flaking received increasingly serious attention by Russian metallurgists. Its source is not mentioned in the Seminar, but it was probably the consequence of the 1935 German discoveries which rapidly spread throughout the technical world.

However, the hydrogen theory adopted a particular form in Russia, differing in important respects from concepts commonly discussed in U. S. literature. Grdina and Zubarev are its progenitors; and theirs is the opening article in the book. Incidentally, no formal recognition of American work appears either here or throughout remaining chapters, although by inference the authors are fairly well acquainted with American rail practice. A single article by England's J. H. Andrew in 1942 on hairline cracks suffices for the background of their discussion; and the authors proceed from there to develop a methane theory on the basis of physicochemical data in Schenck's book of 1932-34, translated into Russian in 1935. The theory that they evolve is the following in outline:

A—Thermal and transformation stresses play only a negligible role in the development of flakes, the fundamental cause rests with hydrogen.

B—The principal function of the stresses developing during cooling is probably to nucleate microscopic voids which open into the surface of ferrite-cementite boundaries.

C—Elemental hydrogen in steel may have three forms: A—molecular H_2 in voids, B—atomic H dissolved in either austentite, ferrite, or cementite, and C—hydrogen adsorbed on surfaces.

D—In flaking, only atomically dissolved H is the primary active principle, this is subsequently converted into entrapped H_2.

E—The pressure of H_2 precipitating from the solid is insufficient to fissure the steel in itself, but far greater pressures arise when further reaction occurs to produce methane.

F—An hypothesis combining the formation of microfissures and the production of entrapped methane then readily explains the principal features of flake development, also flake prevention, in carbon and low-alloy steel; and it clarifies in general the entire range of characteristics relating to microstructure, effects of temperature, occurrence of an incubation period, etc.

G—As both a natural consequence and a proof of the proposed flaking mechanism, subsequent subcritical annealing of flaked steel will disclose graphitization of the pearlitic cementite adjacent to the fissure.

H—Below A_1 the hydrogen separates from solution; a rate maximum lying in the range 500° to 620°C (930° to 1150°F).

I—Prevention of flaking accordingly depends upon removal of the hydrogen by isothermal

CARL A. ZAPFFE is a Consulting Metallurgist in Baltimore, Md.

Table I. Russian Railway Engineering Steels as of 1950, Class IIB, Group 7 Standards

Russian Mark	C	Mn	Si	Cr*	Ni*	Application
Axle steel	0.30 to 0.45	0.50 to 0.90	0.15 to 0.35	—	—	Axles of coaches and tender
Axle steel	0.35 to 0.45	0.50 to 0.80	0.15 to 0.35	<0.30	<0.50	Locomotive axles
45G2†	0.40 to 0.50	1.40 to 1.80	0.17 to 0.37	<0.30	<0.30	Axles of steam locomotives, coaches and trolleys
Tire I	0.50 to 0.65	0.60 to 0.90	0.15 to 0.35	—	—	Tires on passenger locomotives
Tire II	0.55 to 0.70	0.60 to 0.90	0.15 to 0.35	—	—	Tires on coaches
Tire III	0.60 to 0.75	0.60 to 0.90	0.15 to 0.35	—	—	Tires on tenders
Tire IV	0.65 to 0.80	0.50 to 0.80	0.15 to 0.35	—	—	Drive wheels on freight locomotives
Rail:						
Open hearth	0.53 to 0.70	0.60 to 0.90	0.15 to 0.30	—	—	Rails

* Blanks in these columns signify "not specified."
† The "G" in 45G2 is the Russian code for manganese.

treatment in that range, whether followed or not by retarded cooling; and a satisfactory schedule can be reduced to mathematical formulation once the transformation characteristics for the steel are known.

Experimentation

Experimental 7-ton open hearth heats of rail steel were saturated with hydrogen using 5/16-in. steel pipe and tank H_2 at 30 to 120 atm for periods ranging from 1 to 6 min. This is similar to the work of Cramer in America, although no mention is made of his work. Extensive tabulations of data are given for flake count vs mechanical properties, and for a number of heat treatments. Rail heads showed as many as 1278 flakes on their cross-section. Both ½ and 8-m lengths were studied (approx 1½ and 26 ft). The principal results were as follows:

A—Isothermal treatment at 550° ± 25°C (1022° ± 45°F) for 2 hr guaranteed a freedom from flaking even in hydrogen-saturated steels.

B—Preliminary cooling to 300°C (572°F), 200°C (392°F), or even 150°C (302°F) did not form flakes in the experimental rails if the temperature was immediately raised to 550° to 600°C (1022° to 1112°F) for the 2-hr treatment.

C—Similarly a slow cool from the range 550°-375°C (1022°-707°F) down to 150°C (302°F) over a period of 5 hr guaranteed an absence of flaking.

Recommendations

On the basis of a great number of studies contributed by the various authors, a *quality* program was more or less agreed upon, although details in scheduling differed among the various plants. Some recommended thermocouple control for the soaking treatment, the junction to be placed tightly against the rail just beneath the head and from 3 to 6 ft from the end. Rails in one plant were placed in groups of 12 on a hot frame at 650° to 680°C (1202° to 1256°F). When a temperature near 620°C (1148°F) was reached, and never below 500°C (932°F), the pack was moved by a magnetic crane into a slow-cooling pit, and was not to be removed in less than 6 hr after covering. The exact schedule was 5 hr 30 min for the summer period April 1 to September 30, and 6 hr 30 min for the winter period October 1 to March 31.

In another plant, rails were loaded in a box in an operation requiring 20 to 25 min, the temperature at the time of closing the lid being not less than 350°C (662°F). They were held for 4½ hr, with 30 min allowed for unloading.

Special Studies

Further chapters concern some interesting special studies. Tikhovski describes work at the Ukranian Scientific Research Institute on a sorbitizing treatment of rail ends to counteract a problem of premature wear which affects about 5 pct of the Russian rail output. This, incidentally, is stated to amount to more than 130 million gross tons. Kazarnovski discusses high-frequency induction hardening of rail ends; and Shchanov describes some exploratory heat treatments on rail ends, web, and bolt holes. Koreshkova has an interesting article on heavy-rail profiles, principally comparing Russian products with what is stated to be a 50 kg rail produced in America in 1942. The book then closes with several chapters on manganese grades of rail steel utilizing 1.0 to 2.0 pct Mn with carbon reduced to approximately 0.50 pct.

Kontorovich describes the Russian work on flaking and forging practice very poorly in his 1945 publication, *The Heat Treatment of Steel;* but Morozov gives a good coverage of general hydrogen theory in *Hydrogen and Nitrogen in Steels,* published in 1950. Furthermore, he refers to a prewar *Metallurgizdat* published in 1939 on *Flakes in Steel: Answers to Questionnaire*; then to an annotated bibliography on flaking by Sorokin in 1940; to *Reports on the All-Soviet Conference on the Problem of Flakes in Steel* in 1941, mentioned earlier in the present discussion; and finally to a 1950 book expressly on flakes in steel, by V. Dubov. None of these has yet come to the attention of the present reviewer. Finally, two recent and extremely informative Government publications, *Metals and Alloys in Chemical Machine Apparatus* and *Introduction to Metallurgy,* authored by Slavin and Shteiman and by Pogodin-Alekseev et al. respectively provide a comprehensive description of Soviet steel technology. A tabulation of rail steel standards extracted from the latter is given in Table I.

Comparison of the rail analysis in this tabulation with that of American practice shows C and Mn each running about 10 points lower in the Russian products; this was also a matter of discussion at the Seminar. In view of the fact that America adopted the 50 kg rail about 1900 and the 65 kg in 1916, and now utilizes weights up to 155 lb per yd (77 kg per m), Russian practice apparently lags in this respect, as well as in their rolling shorter lengths of approximately 26 ft as compared to our 39 ft standard. However, the work described at their Rail Seminar goes far toward closing any technological gap that has previously existed. The contribution is impressive, deserving a much more thorough study than the brief review afforded here.

Gas Combustion Practice Described For Copper Smelters of the Southwest

by Harold Foard

NATURAL gas as currently furnished to smelters of the Southwest has a high heat value of approximately 1100 Btu per cu ft, and a sp gr of 0.66. One cu ft requires approximately 10.7 cu ft of air for combustion, or 19.2 pct oxygen in the gas-air mixture.

The theoretical flame temperature of natural gas (uncorrected for dissociation of CO_2 and H_2O) is approximately 3700°F, or 200° to 300° less than that of oil or coal. At best, not over 75 pct of the theoretical flame temperature can be attained in practice. Complete combustion within the shortest possible time is therefore desirable to develop a maximum temperature difference between the flame and charge and to achieve an efficient transfer of heat by a maximum length of travel for the combustion gases. Speed of combustion is identical with speed of mixing, and burner design is therefore of primary importance.[1]

Burners may be separated into two general classes, one using air under pressure, and the other inducing air at atmospheric pressure by means of gas jet energy. One plant has found cold air under pressure satisfactory at their moderate operating rate of 115,000 cfh. Another plant found a similar installation unsatisfactory at an operating rate of 185,000 cfh, although their cross-sectional combustion area was approximately 200 sq ft.

Forced air supply at a preheat temperature of 650°F is used in one very interesting installation. A multi-jet burner system delivers the gas, and preheated air amounting to 65 pct of the air needed for combustion, to an external combustion chamber. Turbulence within the combustion chamber aids in mixing the primary gas-air mixture with secondary air, and the incandescent interior of the combustion chamber allows the development of high flame temperatures.

Multi-jet burners dependent upon cold induced air have not been generally successful on reverberatory furnaces and have been replaced with barrel burners in several instances. Barrel burners as originally used were cast iron with venturi throats; the present trend, however, is to plain burners made of 8 to 10-in. pipe with or without approach cones. These burners are cheap, easy to handle, and lend themselves readily to experimental development for improved air injection and mixing.

Barrel burners shown in Fig. 1 are in use at the Miami, Ariz. plant of the International Smelting & Refining Co. and are made of 6-ft lengths of 8-in. pipe. No cone or venturi throat is used. Gas spuds have a 7/16 in. diam and changes in flow are made by adjustment of header gas pressures. Burner characteristics have been determined at varying rates of gas flow. The optimum gas setting is considered to be that which results in closest possible approach to the stoichiometric percentage of oxygen. Under former conditions using natural gas of 0.63 to 0.64 sp gr, each burner would deliver a stoichiometric gas-air mixture at fuel rates up to 12,000 cu ft of gas per hr. Present gas supply of over 0.66 sp gr has reduced individual burner capacity to approximately 10,000 cu ft per burner hr.

HAROLD FOARD is Superintendent, International Smelting & Refining Co., Miami, Ariz.

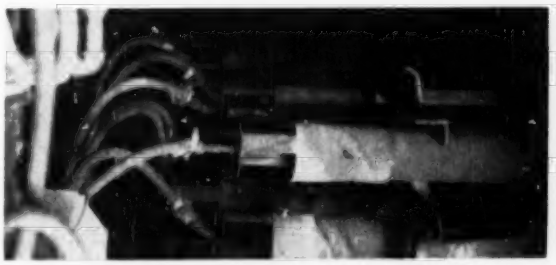


Fig. 1—Barrel burners are made of 6-ft lengths of 8-in. pipe and are easily adaptable to experimental development.

Grids, similar to those of a laboratory Meker burner, are used. They are made of 3/4x1/16-in. steel with 1-in. square openings. The throat to grid burner length is 60 in. At a gas flow of 10,000 cfh (header pressure, 52 psig) a pressure of minus 5 in. H_2O is found at the burner throat. That negative pressure gradually decreases to zero at 30 in. downstream. A gradual increase in pressure is then observed until, at a point 1 in. upstream from the grid, a pressure of plus 0.8 in. H_2O is shown. Oxygen content of the gas-air mixture at the grid, under the conditions quoted, is 19.2 pct, and is uniform from the pipe to the center of the stream.

Observation of grid burners shows their flame characteristics to differ from those of a straight pipe burner in exactly the same manner as the flame of a Meker burner differs from that of a Bunsen burner. In addition to equalizing velocities across the gas-air stream, the grids act as effective flame arresters and permit a 75 pct turndown without flashback.

Combustion

For all practical purposes the variables of pressure and temperature encountered in reverberatory furnaces are fixed. An exception to this statement occurs, in the case of preheated combustion air in which the flame speed increases approximately as the square of the absolute temperature of the mixture. Flame speed is of importance because the flame front is located at that point where the gas-air downstream velocity and the upstream flame velocity are equal.

On a practical basis, therefore, rapid completion of combustion is assured by intimate mixture of gas and air, in stoichiometric proportion, in the primary burner stream. The rate of combustion of such a mixture, to within 99 pct of completion, has been

estimated at 2.16 million Btu per hr per cu ft of combustion space.[1] Assuming a cross-sectional combustion area of 120 sq ft and a fuel rate of 150,000 cfh, combustion should be substantially complete within a distance of 7 in. from the flame front.

Infiltration of air through fortuitous furnace openings, and acceptance of this secondary source of air as a necessary evil, is a major factor in lengthening the combustion zone. Avoidance of excess air in furnace exit gases by means of a decrease in the primary air supply, and utilization of secondary air for combustion, extends the combustion zone by the length required for the mixing of secondary air. Such mixing proceeds by diffusion across the interfaces of fuel-rich and oxygen-rich zones, accentuated by turbulence. The rate of mixing cannot be predicted, but lack of efficiency of the process is indicated since excess oxygen and carbon monoxide are frequently found to be co-existent in the furnace gases.

Position of the flame front has been found, by field observation, to be of primary importance in combustion efficiency. A series of tests recently made at Miami indicated a decrease of approximately 10 pct in fuel consumption per ton of charge as a result of a change in primary air-gas composition. At the beginning of the tests furnace gases showed an Orsat analysis of 12.0 pct CO_2 plus SO_2, and 0.4 pct O_2. The primary mixture was 18.8 pct O_2, or approximately 84 pct of the air necessary for complete combustion, the balance of the air entering through secondary ports in the bridge wall. Closing of the secondary ports and increasing the primary mixture to 19.2 pct O_2 resulted in the same furnace gas analysis. Fuel consumption per ton dropped immediately, front-end temperature dropped 100°F, and the bridge wall became visibly hotter.

Furnace charging, pouring of converter slag, and other interruptions interfere with the constancy of operation. Such interference is unavoidable and has been found less deleterious than any attempt to utilize air from those sources for combustion at the expense of the primary mixture.

Controls

Gas flow, or the amount of fuel burned, is dependent upon the rate of operation desired, and automatic adjustment of that rate could function only as a part of automatic temperature controls. The practicality of automatic temperature control is subject to question. The purpose of the furnace is to smelt the charge at an established rate, not to maintain a specific temperature. Assuming equal excellence of combustion and correct charging, a furnace operating on a soft charge is colder than when operating on a difficult charge because of the greater rapidity of heat transfer.

Oxygen recorders have been studied with a view to control adaptation. An automatic control to maintain a perfect primary mixture in spite of variations in atmospheric conditions and gas density would be of value, but controls on the basis of furnace exit gas analysis would be difficult to apply. Adjustment of primary air on the basis of furnace gas analysis is incorrect in principle, and secondary air from fortuitous openings is not subject to controls.

Draft recorders are in general use throughout the industry, and many plants have installed automatic draft controls. Because of structural details some plants have installed fixed, or partially movable, dampers in the reverberatory arch to divorce furnace pressures and velocities from the draft requirements of waste heat boilers.

Fig. 2—Under proper combustion control a positive pressure zone, approximately 60 ft from the burner wall, puffs in a manner similar to breathing.

Although furnace draft is usually considered as a whole, it would seem desirable to consider it as the resultant of two pressures: A—The negative pressure produced at the bridge-wall by the injector effect of the burner streams, and B—the negative pressure existing in the front part of the furnace as the result of the stack draft. Within normal operating limits changes in stack draft have small effect upon bridge-wall pressures and, when burners are inducing 100 pct of the combustion air, no measureable effect upon combustion.

Tests have been made on a 120x25-ft furnace operating at 140,000 cfh gas flow, 19.2 pct O_2 in the barrel mixture, and with total bridge-wall openings of 100 sq in. Reverberatory arch draft, normally 0.03 to 0.05 in. H_2O, was varied within the range 0.01 to 0.10 in. H_2O. Bridge-wall drafts were varied from 0.08 to 0.12 in. H_2O compared with the ten-fold variation in reverberatory arch draft. A major change was noted in the magnitude of the furnace pressure zone. Under a normal reverberatory arch draft of 0.04 in. H_2O, draft at the bridge-wall amounted to 0.10 in. and gradually changed to a very slight positive pressure at a point 60 ft in front of the bridge-wall. From that point forward draft increased as the effects of stack draft became apparent. Under the low stack draft of 0.01 in., the positive pressure zone began 25 ft in front of the bridge-wall and extended for 35 ft down the furnace. Analysis of barrel mixtures were made over the draft range between 0.03 and 0.08 in., but no change was found in the oxygen content.

Positive furnace pressures and minimum gas velocities have been found to give the best results in practice. Working conditions in the vicinity of operating furnaces prohibit the use of positive pressure beyond a very slight extent, and automatic draft control could be of value in maintaining the fine adjustment necessary. Controls set to a given furnace pressure do not, however, differentiate between pressure changes caused by atmospheric conditions and those caused by a charge gate left opened and forgotten. Although controls are a useful tool, they cannot substitute for the watchful eye of a foreman who insists that his furnace be kept closed as tightly as possible and that the pressure zone should *breathe* as illustrated in Fig. 2.

References

[1] W. Trinks: *Industrial Furnaces.* (1942) 2nd edition, Vol. 2, p. 37. New York. John Wiley & Sons, Inc.

[2] W. J. Wohlenberg: The Influence of Reaction Interface Extension in the Combustion of Gaseous Fuel Constituents. *Trans.* ASME (April 1948) **70**, p. 143.

Sintering Zinc Concentrates on the Blackwell 12 by 168 Ft Machine

by A. E. Lee, Jr.

THE Blackwell Zinc Co., Inc., a subsidiary of the American Metal Co., Ltd., operates a horizontal retort zinc smelter at Blackwell, Okla. The plant has 14 furnace blocks of 800 retorts each, fired with natural gas on a 48 hr cycle. Over 13,000 tons of zinc-bearing material, chiefly sulphide flotation concentrates, are treated monthly to produce slab zinc and high lead-cadmium fume.

In 1942 a program of rebuilding and modernizing the smelter was started. By 1947 furnace smelting capacity had been increased to a point where roasting and sintering facilities were inadequate, and it was necessary to purchase oxidized materials to supplement sinter production. The seven 210 ft Ropp roasters and three 42 in. x 44 ft Dwight-Lloyd machines then in use had been in service at least 20 years and were in need of major rebuilding. Thus it was entirely practical to consider all new equipment and a change of method rather than rebuilding and repairing obsolete units. A study of the problem indicated that roasting as such could be eliminated and roasting and sintering accomplished in one step by a modification of the Robson process,[1] which had been used since the early 1930's by the National Smelting Co., Ltd., at their plants at Avonmouth, England, and Swansea Vale, South Wales.

Francis P. Sinn, General Manager, Zinc Smelting Operations, The American Metal Co., Ltd., who was familiar with the practice in England, suggested the use of one large machine for the entire operation from concentrate to sinter. One step sintering appeared to best meet Blackwell's plant requirements and indicated substantial savings in labor, gas, coal, and repair costs.

Choice of Machine Size

The sinter machine size was set at 12x168 ft for a rated capacity of 540 tons per day. This tonnage, produced on a five day week, would meet the seven day requirements of the 14 furnace blocks. The one large machine was quoted at a lower cost than two or more 6 ft wide machines of similar total capacity. Further, the larger machine could be housed in a smaller structure and only one set of equipment for charge preparation and delivery and for disposal of sinter cake was needed. One machine on a five day week made possible a concentration of the skilled operating personnel and required less men than a plant including two or more machines and related equipment circuits. Fewer units of equipment meant less maintenance, and the two down days weekly allowed ample time to repair and, if necessary, to make up lost production.

Experience had indicated better sintering quality and rates with larger masses of material, not only on wider machines, but also in deeper beds. The ratio of windbox perimeter to area for the 12x168 ft machine is 0.179, compared to 0.353 for a 6x102 ft machine and 0.617 for a 42 in. x 44 ft machine. This meant less air leakage with resulting fan power savings and less spoilage of charge along the pallet sides.

A. E. LEE, JR., Member AIME, is Superintendent, Blackwell Zinc Co., Inc., Blackwell, Okla.

Discussion on this paper, TP 3668D, may be sent, 2 copies, to AIME by Feb. 1, 1954. Manuscript, Dec. 15, 1952; revision, Sept. 8, 1953. Los Angeles Meeting, February 1953.

Performance

Initial operation of the new sinter plant was made in November 1951 and regular production attained late in December. The average product sinter output during 1952 and the first half of 1953 has been 18.2 tons per hr. The average for one month has been as high as 22.4 tons per hr. Considerable experimenting with varied operating conditions accounts in part for the below capacity — 24 tons per hr — average output, and work to further improve production rate continues.

A typical sinter analyses is 66.0 pct Zn, 0.3 pct Pb, 0.1 pct Cd, 0.3 pct S, 8.0 pct Fe, 2.0 pct SiO_2, 0.8 pct CaO, and 0.2 pct MgO. Use of this material has made possible increases in furnace burden and improved furnace operation over the former practice using sinter made from Ropp roasted concentrates. Better lead and cadmium elimination in sintering has permitted the furnace production of slab zinc lower in lead and cadmium.

Anticipated economies of operation have largely been gained. The sinter plant is operated by seven men per 8 hr shift — one head operator, three equipment operators and three sweepers — plus one oiler on day shift only. While it has been necessary at times to operate seven days a week to produce the required sinter tonnage, the five day work week usually has been adequate. Consumption of natural gas for sinter bed ignition is 200,000 to 300,000 cu ft per day.

Green Ore Sintering Practice

The 30 to 31 pct sulphur content of the −200 mesh zinc concentrates is the fuel used to sinter the charge, no coal addition being required. In the feed to the machine, sufficient concentrates are added to crushed return sinter fines containing 0.3 to 0.5 pct sulphur to produce a charge averaging 5.0 to 6.5 pct sulphur. Since the return sinter used in Blackwell's practice is varied from −½ to −⅛ in., the actual sintering mixture of fine sinter and concentrates is somewhat higher in sulphur. The coarser sinter particles are too large to resinter and merely aid porosity in the sinter bed. The ratio of concentrates to return sinter in the charge ranges from about 1:4 to 1:5.5. Variations are based on the appearance of pried up bed sections, bed exit gas temperature trends, windbox suctions, and return sinter size. Sufficient sulphur must be used to obtain fritting of the charge into a soft sinter cake and to aid in the elimination of lead and cadmium. Excessive feed sulphur will result in partial slagging of the cake impairing porosity and prolonging sintering time.

The Transactions papers appearing in the Journal of Metals during 1953 will subsequently appear in AIME Transactions Volume 197, and may be permanently referenced to that volume.

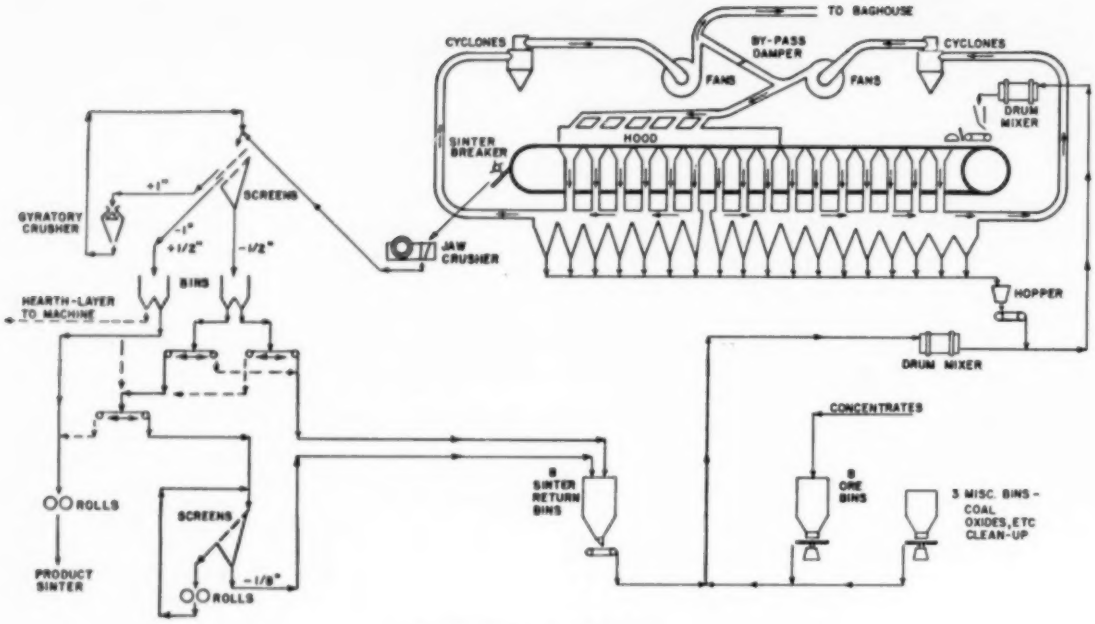


Fig. 1—Sinter plant flowsheet.

Good elimination of lead and cadmium is obtained with this process without the aid of salt or other additives. This is in part due to the probability that each concentrate particle will pass over the machine from five to six and a half times before escaping the circuit as oversize product — once as concentrate and four to five and a half times as return sinter. Since the sinter cake from the machine is crushed and screened until 82 to 87 pct passes a ½ in. screen, only that portion which has been well sintered, and thus subjected to maximum heat, escapes as + ½ in. product. The initial intimate association of lead and cadmium to the sulphur fuel within the concentrate particle also promotes good elimination.

Charge Preparation

Schematic flow of materials through the sinter plant is shown in Fig. 1. Concentrates and return sinter fines are stored in sixteen 300 ton capacity circular steel bins with 60° conical bottoms. Eight bins receive concentrates averaging 5 to 15 pct water by overhead conveyor from the ore unloading and storage area. The 6 ft 6 in. diameter variable speed table feeders discharge the wet concentrates from these bins to a belt conveyor system feeding the machine. Each bin is fitted with a ring of compressed air ports halfway up the bottom cone to overcome bridging of wet ore. The remaining eight bins receive return sinter from the discharge circuit of the sinter machine via a twin conveyor system, permitting simultaneous delivery of two separate materials. Variable speed belt feeders discharge these bins to the sinter machine feed conveyor system. Ordinarily only two bins are used at a time for feeding return sinter to the charge. The remaining six bins are used variously for storage of good quality returns drawn upon in periods of operating difficulty, poor quality returns gradually fed into the circuit, and crushed product sinter for later resintering with coal if needed. Coal, clean-up, carbonates, refuse zinc oxide, and other miscellaneous materials requiring sintering are stored and fed from three smaller bins in the same area.

Material removed in the windboxes and cyclones from the sinter machine exit gas system is continuously collected by a belt conveyor system and delivered to a small surge bin. The collect is fed by a variable speed feeder to the sinter machine charge conveyor system.

Mixing of the feed materials is effected in two stages by a pair of 6 ft 6 in. diameter x 16 ft 6 in. rotating drum type mixers in series. Each mixer has a single off-center, counter rotating paddle shaft, water sprays for wetting the charge, and a brick lining to minimize drum wear and wet charge build-up. The first unit accomplishes preliminary mixing and breaks up most of the remaining concentrate lumps. In the second mill, final mixing and moistening to 7 to 9 pct water occur, the feed discharging to an inclined belt conveyor emptying to a large swinging spout over the sinter machine.

Sintering

Charge is distributed by the swinging spout over the width of a 154 in. wide variable speed belt conveyor. Belt speed is regulated so that a uniform ribbon of charge, 3 to 4 in. thick and the full width of the machine, is discharged against a sloping steel bed leveling plate, sliding from there to the grates. Vertical distance from the top of the belt to the grates is 38 in.

Urban[2] has described the mechanical design and features of the 12x168 ft machine. Fig. 2 shows about one-third of the machine, looking toward the feed end. Grate bars are Helena type with ⅜ in. slots and are made of chrome-nickel alloy. The original set, less a small breakage loss, has been in service since November 1951 and is expected to have an overall life of at least five years. Pallet speed over the 168 ft length of the 16 windboxes may be varied from 3.5 to 7.0 ft per min. Bed depths have ranged from 6 to 13 in., the latter being flush with the top of the pallet sides.

Windboxes are steep sided hoppers designed to allow high speed exit gases to sweep any material

Fig. 2—View of 12x168 ft sinter machine, looking toward the feed end.

drawn through the grate openings into rectangular downcomers outside the machine frame. The downcomers discharge to large balloon flues below the machine where the gas velocity is only 1000 to 1500 ft per min, allowing most of the windbox drippings to settle out. Bottoms of the balloon flues consist of steep sided hoppers, discharging through flap-trap valves to the clean-up conveyor system.

Sinter Cake Crushing and Screening

From the discharge end of the sinter machine the cake falls to a sloping dead-plate and is broken to −9 in. by a special sinter breaker. A series of 4 ft diameter, 1¾ in. thick steel claws clearing the dead-plate about 4 in. and mounted on a slowly rotating shaft make up the breaker. From the dead-plate the sinter falls to a 32x42 in. jaw crusher, is broken to −5 in., and carried on a 42 in. wide apron conveyor to a pair of 5x10 ft double-deck shaker screens. The +1 in. top deck material is closed-circuited through a gyratory crusher back to the screens.

Sinter on the bottom ½ in. opening screen flows to a pair of hoppers arranged for spill one to the other. One side delivers to a conveyor system supplying hearth layer to the sinter machine but is only used when a very large part of the return sinter is crushed to −⅛ in. The other side delivers usually to the product sinter circuit but may be sent back to the return sinter bins through a closed-circuited 16x42 in. roll crusher and ⅛ in. screen when resintering is desired. Sinter in the product circuit is crushed to approximately −¼ in. and delivered by conveyor to the furnace charge mixing plant.

The −½ in. sinter fines fall to a second pair of hoppers also arranged for spill one to the other. Discharge from these two hoppers is controlled by separate variable speed and reversible feeders. When one or both feeders operate in one direction, that sinter passes to the return sinter bins as is; i.e., −½ in. When one or both feeders operate in the reverse direction, that sinter delivers either to the product sinter circuit or back to the return sinter bins through the ⅛ in. sizing circuit. This arrangement enables the operator to vary the ruling size of the return sinter in any proportion from all −½ in. to all −⅛ in.

Machine Exit Gas System

Gases from the collector main balloon flues servicing the six windboxes nearest the discharge end of the sinter machine pass through cyclones to a pair of draft fans connected in parallel. Each of these fans is designed to handle 117,000 cfm of 235°F gas at −20 in. water. Exit gases are piped to a baghouse for lead-cadmium fume collection.

Gases from the collector main balloon flues servicing the ten windboxes at the feed end of the machine pass through other cyclones to a second pair of fans in parallel. Each of these fans is designed to handle 103,000 cfm of 215°F gas at −28 in. water. Exit gases are piped either to the baghouse or to a recirculation hood over the last nine windboxes at the discharge end. Purpose of the recirculation system is to reduce by nearly half the gas volumes filtered by the baghouse. Since most of the lead and cadmium eliminated leaves the bed near the discharge end, the gases recirculating from the first ten windboxes contain relatively little fume. An automatic damper in the flue to the baghouse is controlled by the hood pressure to prevent gases from blowing out around the hood.

Baghouse

Collection of the lead-cadmium fume is made in ten Norblo No. 936-A automatic dust arresters, totaling 9360 bags, each 6 in. in diameter x 8 ft 3 in. long. The ten units are arranged in pairs over double width hoppers and serviced by five double inlet fans. Each fan is rated at 50,000 cfm of 200°F gas at −8 in. water. The dust is removed from the hoppers by a system of screw conveyors and elevator to a large storage bin from which shipment is made.

Filter bag cloth is unnapped, 4.2 oz, continuous filament orlon. Useful life of an orlon bag under normal operating conditions is about one year, the fabric porosity at that time having reduced to about 10 pct of original value. Patching of a continuous filament orlon bag for wear in a year's time is unusual.

The interval between bag shakings has been varied from 15 to 45 min, the latter time now regular practice. Inlet gas temperature to the baghouse is controlled at 240°F by automatic bleed-in of outside air. Lime additions to the inlet gases are used to maintain a relative alkalinity of at least 11 pct in the dust collected in a manner similar to that described by Shinkoskey.[3]

Acknowledgment

The basic metallurgical conceptions and practice embodied in the new sinter plant were developed by Francis P. Sinn, of The American Metal Company, Ltd. Complete design of the plant was made, under the direction of W. J. Urban, by the American Ore Reclamation Co., Chicago. The assistance and advice of Chester Skinner and Douglas Stafford at Blackwell in the preparation of this paper are gratefully acknowledged.

References

[1] T. B. Gyles: Horizontal Retort Practice of the National Smelting Co., Ltd., Avonmouth, England. *Trans.* AIME (1936) **121**, pp. 418-426.

[2] W. J. Urban: The World's Largest Sintering Machine. *Blast Furnace and Steel Plant* (1951) **39**, pp. 339-342.

[3] R. E. Shinkoskey: Conditioning Dwight-Lloyd Gases to Increase Bag Life. *Trans.* AIME (1950) **188**, pp. 608-609; JOURNAL OF METALS (March 1950).

Some Observations of Slag-Metal Relations In the Acid Open Hearth Steel Furnace

by G. R. Fitterer

Trends in slag composition in acid open hearth practice, particularly the variation in iron and manganese oxides during refining, are reviewed. A procedure which is currently being used to control the refining reactions is described and partially explained through slag phase diagram considerations. In addition, the ionic nature of these slags is considered and it is proposed that silica combines with the oxide ion and forms a series of complex silicate ions. The effect of basic oxides such as FeO, MnO, and CaO is apparently additive in furnishing the oxide ion for this purpose.

IT is now possible to control[1,2] the refining of steel in an acid open hearth furnace to a surprising degree. This control has been brought about through the knowledge and use of several facts and tests. These are: 1—A planned charge analysis based on a knowledge of the type of fuel, the bath depth, etc. 2—Knowledge and control of rate of fuel input as well as its method of atomization, if any. 3—Determination of the slag fluidity. 4—Bath temperatures (use of the Pt-Pt-Rh thermocouple). 5—Periodic determination of carbon content (use of the Carb-analyzer or Carbometer).

Through the use of these control methods, a heat may be made to "melt-in" with or without residual manganese and silicon. The rate of refining or carbon elimination may be controlled accurately, and the desired tapping (or "go-ahead") carbon may be approached at a rapid or slow rate according to preference and type of steel being made. Thus operating time may be predetermined and greatly reduced. Further, all of the refining can be done without any ore or other oxidizing additions, and the heat may be brought to the desired tapping temperature simultaneously with the attainment of the desired carbon analysis.

This control procedure is being used in most acid plants in the United States today and has been described.[1, 2] Although the slag metal relations are sufficiently well known to control the heat as stated, yet it is possible to account for only about two-thirds[2] of the O_2 which must have been used for the elimination of the carbon and other metalloids. Phase diagram studies[3] of the slags, slag weights, the metal particle theory,[4] ore additions, limestone additions, etc., may all be taken into consideration; yet, the mechanism of oxidation and source of all the oxygen remain to be explained. This paper reviews some of the principles upon which the control methods were based and proposes other possibilities regarding the unexplained phenomena.

G. R. FITTERER, Member AIME, is Dean, Schools of Engineering and Mines, University of Pittsburgh, Pittsburgh, and Director of Research, Acid Open Hearth Research Association, Inc.

Discussion on this paper, TP 3671C, may be sent, 2 copies, to AIME by Feb. 1, 1954. Manuscript, Feb. 16, 1953; revision, Sept. 18, 1953. Los Angeles Meeting, February 1953.

Old and New Acid Open Hearth Practice

Some of the recent statements in the literature regarding acid open hearth operation are based on old heat data which are not typical of modern American practice. These old heat logs have been responsible for many misconceptions regarding the acid hearth practice and represent heats which do not coincide with modern methods. In recent years, American practice has been altered materially and these changes will be briefly described.

Modern American Practice: A typical log of a modern American acid open hearth heat[1] is shown in Fig. 1 which indicates that the refining time was only two hours, during which the carbon was eliminated rapidly and the bath temperature increased at a fast rate. The manganese and silicon contents of the metal were essentially eliminated and their oxides had become constituent parts of the slag at the "melt-down" period. During the course of the heat, the MnO content of the slag remained practi-

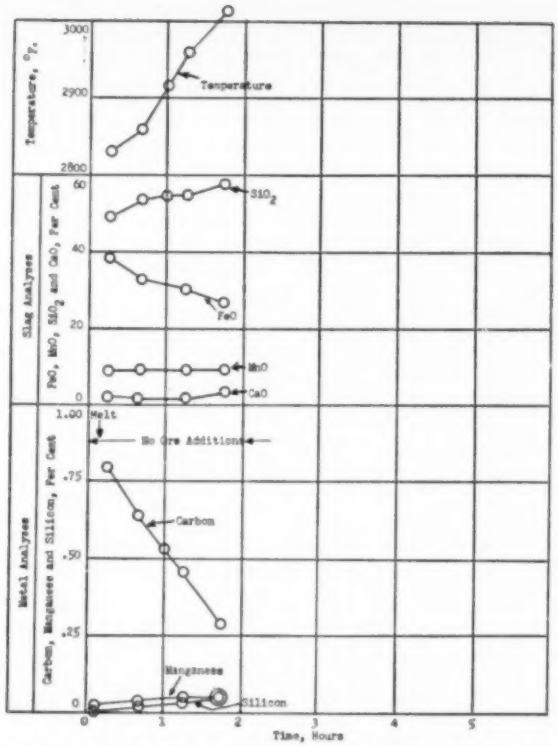


Fig. 1—Log of an acid open hearth heat.[1] American practice, low manganese charge.

cally constant; whereas, the FeO decreased and the SiO_2 increased.

Older European Practice: The acid open hearth practice which was in vogue in this country and in Europe about thirty years ago is illustrated[2] in Fig. 2. The rate of carbon elimination was only about one-half that of the heat in Fig. 1 and the rate of temperature increase was much slower. Throughout most of the second heat, the FeO content remained fairly constant; whereas, the MnO content decreased throughout the heat in direct contrast to modern practice. The SiO_2 content, however, increased as before. The manganese and silicon contents of the metal bath increased throughout the heat.

During the last two hours of this heat, practically no change in any of the slag or metal constituents occurred, but it was the practice to hold heats in the furnace for a long time in the early days in order to give the laboratory time to report analytical results prior to making the final additions.

The older practice resulted in high MnO slags; whereas, the modern slags contain much smaller quantities of this constituent. The differences in the behavior of FeO and MnO in the low and high MnO slags are worth consideration and raise certain important questions regarding slag-metal relations which have not hitherto been answered.

Behavior of FeO and MnO in the Acid Open Hearth

Heats with Low Manganese Charges: In modern American heats, the MnO content of the slags rarely exceeds 20 pct and the average is probably about 12 pct. Furthermore, the MnO content remains essentially constant throughout heats of this type and the percentage merely depends on the quantity of manganese charged. However, as the refining progresses, four main changes occur: 1—The carbon content of the metal decreases. 2—The FeO of the slag decreases and the oxygen content of the metal increases. 3—The temperature of the bath increases. 4—The SiO_2 content of the slag increases.

The trends of carbon, MnO, and FeO in several modern American heats are shown in Fig. 3. The lower MnO points represented samples from heats with higher FeO, respectively, etc. Fig. 4 represents these trends for the single heat which was illustrated in Fig. 1. Obviously, as the heat progressed, the carbon of the metal and FeO of the slag decreased; whereas, the MnO remained constant. This situation is encountered in heats with as much as 20 pct MnO as shown in Fig. 5.

Heats with Intermediate Manganese Charges: If the manganese in the charge is increased so that the ultimate MnO content of the slag increases to about 25 pct, the relative behavior of FeO and MnO begin to change. With this amount of MnO, both the FeO and MnO in the slag decrease as the heat progresses as shown in Fig. 6. It appears that both oxides furnish oxygen for the carbon reaction in this case.

Heats with High Manganese Charges: If the manganese content of the charge is increased so that the ultimate MnO content of the slag exceeds 30 pct, the roles of MnO and FeO in the slag apparently become reversed. In this case the FeO appears to remain practically constant while the MnO decreases throughout the heat, Fig. 7. The trend of MnO in the heat, the log of which was shown in Fig. 2, indicates a decrease in MnO with essentially constant FeO, see Fig. 8. All of the data shown in Figs. 3 to 8 inclusive include heats with and without ore additions which seem to have little or no effect on the relative behavior of FeO and MnO outlined above.

Trend of FeO in the Metal: It is interesting to

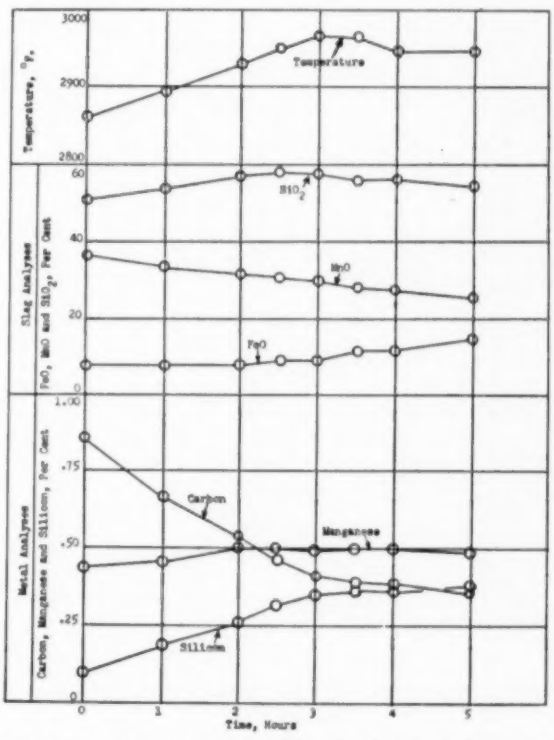


Fig. 2—Log of an acid open hearth heat.[2] Czechoslovakian practice, high manganese charge.

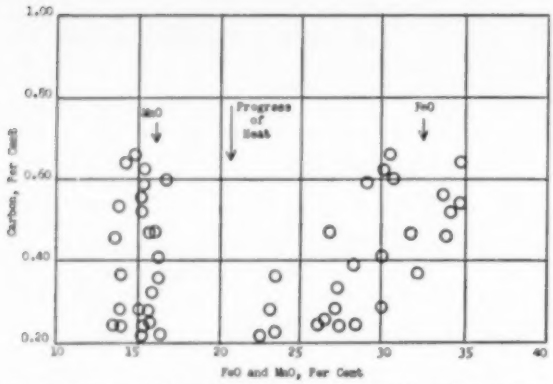


Fig. 3—Usual variation of FeO (and MnO) with the carbon content of the metal. American practice, intermediate manganese charge.

note that the FeO content of the metal increases with decreasing carbon content in the acid open hearth furnace as in the basic. However, the increase in the FeO content of the metal is coincident with a decrease in FeO content of the slag in low MnO slags. In high MnO slags, the FeO content of the metal increases with a decrease in MnO content of the slag. The FeO content of the slag remains constant during these changes as described previously. These relationships between the FeO (and MnO) contents of the slag with the FeO (or oxygen) content of the metal are inverse to those of the basic open hearth process.

Role of Silica and Changes in Slag Weight

The key to the behavior of FeO and MnO discussed above is undoubtedly to be explained through a knowledge of the role of SiO_2 and its relation to the other oxides in such slags together with slag weight studies. For example, in Fig. 9 the trend of SiO_2 with the progress of the heats is illustrated. As the carbon content decreases, the SiO_2 content of the slags increase in a regular manner as shown in Figs. 1 and 2. This occurs whether the FeO or the MnO is changing with the progress of the heat. Both types of heats are plotted in Fig. 9.

A study of the trends[4] in slag weights throughout various heats indicated that the slag weight may decrease, increase, or remain essentially constant depending upon the refining rate and a few other factors. With extremely rapid carbon elimination in which the refining time is less than an hour, for example, the slag weight will decrease somewhat. In this case, the FeO content is rapidly decreased without any time for diffusion of SiO_2 from the furnace walls. In such heats there are few, if any, ore additions and the rate of temperature increase is very rapid. Occasionally, however, with excessive boiling action and bottom repair sand which has not properly set, sufficient mechanical erosion takes place to cause the SiO_2 content to increase abnormally.

Usually in a heat requiring from two to three hours to refine, the loss in FeO content will be balanced by some diffusion of SiO_2 from the banks. However, such heats also require some small ore additions. These factors usually balance to keep the slag weight about constant. Such heats also have a moderate rate of temperature increase, but not as rapid as in the first case above.

In very sluggish heats with a very slow temperature rise, many additions of ore are made and considerable erosion of the banks occurs. Such heats will indicate an appreciable increase in slag weight.

In all cases, however, the SiO_2 content of the slag tends toward the same percentage at a given temperature, presumably because of the phase diagram relationships which are about to be described.

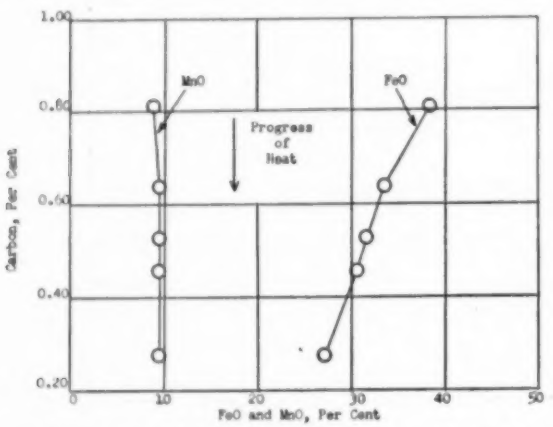


Fig. 4—Variation of FeO and MnO in an acid open hearth slag. American practice, low manganese charge.

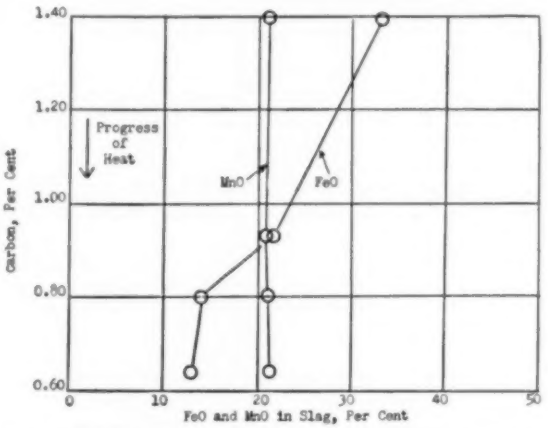


Fig. 5—Variation of FeO and MnO in an acid open hearth slag. American practice, high manganese charge.

Automatic Refining Phenomenon

It has been shown[1] that the acid hearth exhibits an automatic refining phenomenon which is not duplicated in any of the basic processes. Although this phenomenon has been utilized for the past several years by the member companies of the Acid Open Hearth Research Association, the scientific reasons for its occurrence have not yet been explained.

Oxidation and Temperature Changes: As stated previously, as the heat progresses in American practice, the percentage of FeO in the slag decreases while the MnO remains constant. Part of this decrease can be accounted for by the increase in SiO_2 and thus dilution. Some of the decrease can also be accounted for by the transfer of oxygen from the slag to the metal and the elimination of carbon as CO. However, these quantities of oxygen which can be accounted for through the loss of FeO in the slag, taking slag weights into consideration, are much less than the total weight of oxygen actually used for the elimination of carbon. This additional oxygen must originate in the gases above the slag and be

transferred to the metal bath by some process not yet described.

Another factor which is involved in the phenomenon under discussion is the temperature or rate of temperature increase. Through proper adjustment of the charge and the rate of temperature rise, many acid open hearth heats are made without any ore or other intentional oxidizing additions. If the manganese and silicon contents of the charge are properly adjusted according to the fuel in use,[1] the heat may be made to melt-down without residual manganese or silicon. Hence, it melts on a carbon boil.

Under these conditions, the only requirement for oxidation and carbon elimination is an increase in the temperature. If the rate of fuel input is low, the

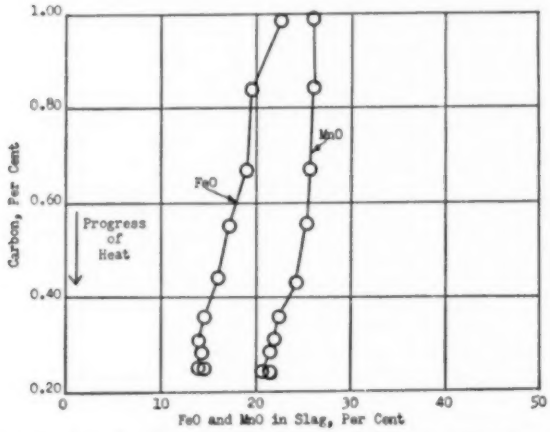


Fig. 6—Variation of FeO and MnO in an acid open hearth slag. American practice, high manganese charge.

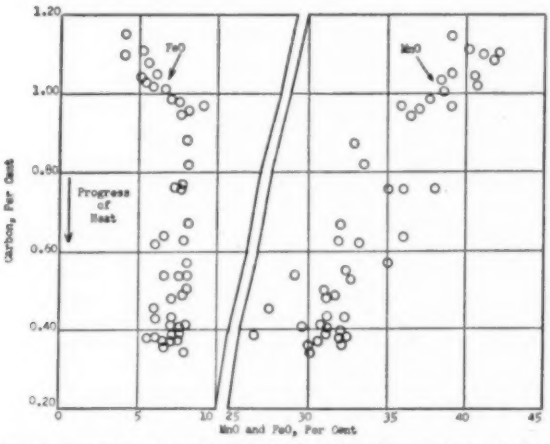


Fig. 7—Variation of MnO (and FeO) with carbon content of the metal. Czechoslovakian practice, high MnO slags.

rate of temperature increase will be correspondingly low, and only a small amount of carbon will be eliminated per unit of time. If, on the other hand, the fuel input and the rate of temperature increase is high, the rate of carbon elimination will be correspondingly high. If the fuel input is high for a while and then suddenly reduced, the carbon elimination will be rapid for a while and then slow up proportionally or stop.

Prior Explanation of the Phenomenon: Previously[2] this phenomenon was explained by the use of phase diagrams as shown in Fig. 10. For example,

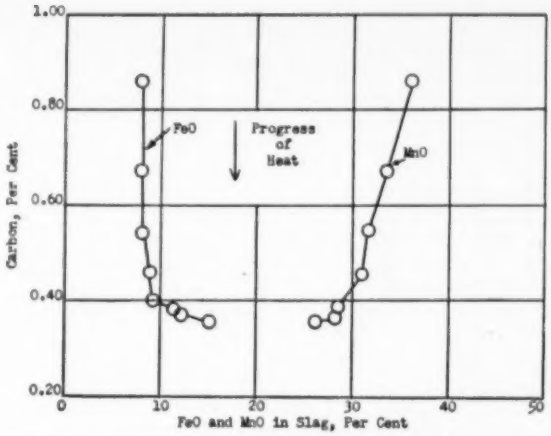


Fig. 8—Variation of FeO and MnO in an acid open hearth slag. Czechoslovakian heat, high manganese charge.

if an FeO-SiO_2 slag is held at some temperature as at point *A* of the figure, it was suggested that it would be saturated with SiO_2 and be essentially inactive. If, however, the temperature is increased rapidly through a high fuel input, the slag temperature might be raised to point *B*. Under this condition, the slag would be unsaturated with respect to SiO_2 and would be active in carbon elimination. If the temperature were held at this point (i.e., 3000°F), the slag would tend to approach point *C* through the loss of FeO to the metal and the oxidation of carbon. At this point, it would again become saturated and essentially inactive. In fact, the carbon content may be held constant under these conditions.

To carry this sequence still further, if the slag at point *C* is cooled to *D*, it would become entirely inactive since solid SiO_2 would be precipitated throughout the slag. By alternately increasing the fuel input and then cutting it back, these steps may be repeated many times. With a medium rate of fuel input, the slag composition might conceivably traverse a line just to the left of line *AC* in a series of small increments as the temperature is increased. The continuous increase in temperature would cause the slag analysis to tend toward an unsaturated condition with respect to solid silica, thus continuously releasing iron oxide for diffusion to the metal bath and reaction with carbon. The continuous loss of FeO from the slag as the temperature is increased

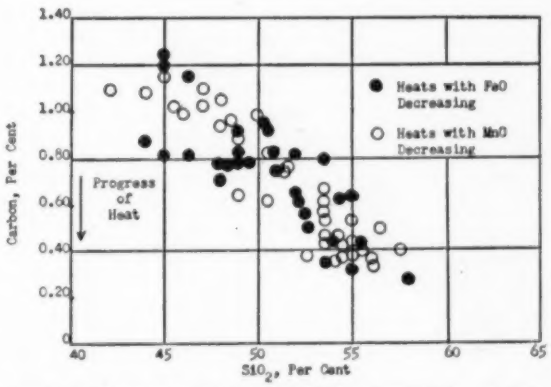


Fig. 9—Usual variation of SiO_2 in the slag during carbon elimination in the acid open hearth furnace.

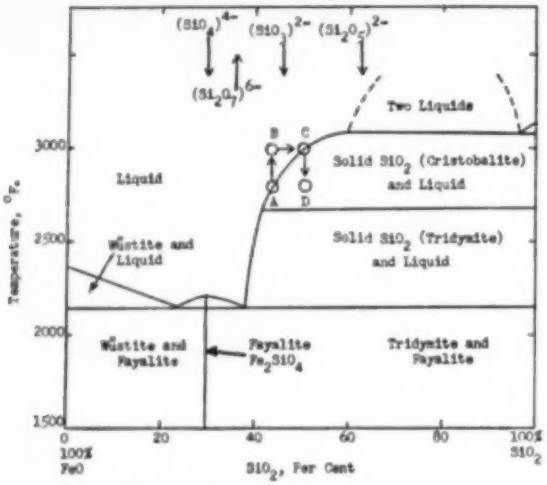


Fig. 10—System FeO-SiO_2 and its role in acid steel refining.

would cause the slag composition to follow a line just above *AC*.

If a greater rate of carbon elimination is desired, a greater rate of fuel input or increased rate of temperature rise will suffice to supply the required FeO (or oxygen) through this mechanism. If the desired tapping temperature is being approached in a given heat and the carbon elimination is to be retarded, a cut-back in fuel input will cause the boil to subside. It can also be seen that if the manganese and silicon contents of the charge are held at a minimum and if the carbon is not overcharged, the entire heat may be refined without any oxidizing additions such as ore. Many heats are currently being made with these factors and the above principles in mind. It might also be stated that the same principles have been applied to the acid electric process[5] with similar results.

This is an overly simplified concept of the mechanism of oxidation and would not be complete without some consideration of the other oxides which normally exist in acid slags. Besides FeO and SiO_2, other oxides such as MnO, CaO, Al_2O_3, and Cr_2O_3 also must be considered as regular constituents, although the latter three rarely exceed two or three per cent.

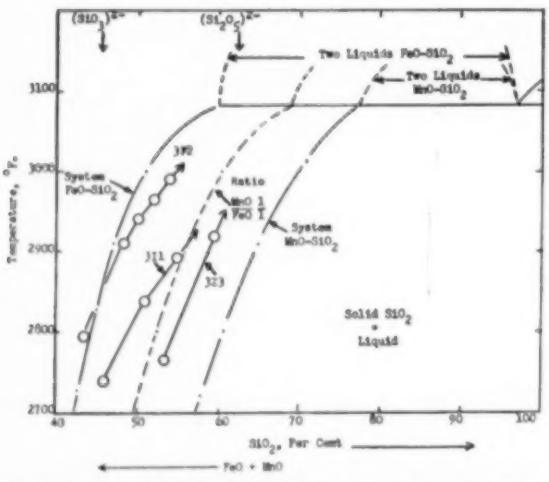


Fig. 11—Systems FeO-SiO_2 and MnO-SiO_2 and acid open hearth slags.

As shown previously, MnO exists in all acid open hearth slags and is inactive under 25 pct, but apparently furnishes oxygen to the bath for carbon elimination, if its content exceeds this amount. For this reason either the ternary system FeO-MnO-SiO_2 or the two binary phase diagrams FeO-SiO_2 and MnO-SiO_2 should be studied with these refining principles in mind.

Because of the uncertainty of the ternary system and for simplification the high silica portion of the two binary systems have been plotted in Fig. 11. Also the SiO_2 contents of slags from three typical heats have been plotted against their respective temperatures in this figure and it is obvious that the compositions of the slags fall between the two liquidus or saturation lines. The trends of the heats from the low to the high temperature indicate a tendency to follow the SiO_2 saturation plane existing between these two binary systems. Hence, it is not improbable that the phase diagram principle described for the simple FeO-SiO_2 system may be applied to the ternary system.

As stated previously, this principle is satisfactory for use in refining but it leaves many questions unanswered. For example, why does FeO apparently furnish the oxygen in a slag containing less than 25 pct MnO and why does MnO become the oxidizing medium above that percentage?

Even small additions of limestone (i.e., 1 or 2 pct CaO in the slag) will release an almost exact pound-mol equivalent of FeO to the metal bath. Obviously, it is more basic but no clue to this degree of basicity is to be found in the phase diagram relationships except that SiO_2 is apparently saturated with much less CaO than with the other two oxides.

Further information should be obtained regarding the behavior of Al_2O_3 and particularly Cr_2O_3 in the acid slags before complete understanding of the process is available.

Ionic Theory of Slags

Because of these and other unanswered questions regarding acid open hearth phenomena, the ionic as well as other theories must be considered for fundamental explanations. The following discussion is admittedly speculative and is presented for the purpose of provoking thought along new lines and with the hope of ultimately linking established acid open hearth slag-metal relationships with a more satisfactory and complete scientific theory.

Possibilities of Compound Formation in Slags: Mineralogists have reported the existence of both the mono (meta) and di (ortho) silicates of FeO, MnO, and CaO, yet particularly in the FeO-SiO_2 phase diagram only $(FeO)_2SiO_2$ or fayalite has been indicated.[6,7]

Many acid open hearth slags have been studied by petrographic[8] and X-ray[9] diffraction methods in the "as-cast," slowly-cooled, and heat-treated conditions, yet no crystalline form of any of the silicates has been observed. This statement should not be taken to indicate that no such molecular associations or embryonal crystals are possible in either the solid or liquid states, but merely that the SiO_2 contents of acid open hearth slags are so great even at "melt-down" that the tendency to crystallize into any inter-oxide compound form is retarded through the tendency of SiO_2 to form amorphous glasses.

Only one type of crystalline species has been identified[9] in recent acid open hearth slags. This is of the spinel family and can be observed when the Al_2O_3 or Cr_2O_3 contents of the slags exceed about 4 pct. The $(FeO)_2Al_2O_3$ and $(FeO)_2Cr_2O_3$ compounds apparently have a strong tendency to form and crystallize even in the presence of the high silica contents of acid slags.

Ionic Theories: As early as 1907 Doelter[10] suggested that the molten iron silicates indicated high electrical conductivity and many other investigators since have checked this observation and concluded also that the conductance is of an ionic nature. In his studies of acid open hearth slags, Herasymenko[11] concluded that they were completely ionized in the molten state. This has much basis of fact.

One of the best reviews of the ionic nature of slags was made recently by Chipman and Chang,[12] wherein it was shown that a new trend of thought was initiated by Lewis[13] who suggested certain revised definitions of acids and bases. He proposed that a basic material such as the oxygen ion $(O)^{2-}$ possesses electrons which are available to enter the electron shell of an atom of various molecular species to form a resulting bonded molecule. A molecular species containing an atom which can receive electrons in its valence electron shell was conversely defined as an acid.

Following this newly defined system, several investigators have developed a series of ideas regarding glasses and other silicates upon which most of the following is based. For example, Sun and Silverman[14] and Sun[15] suggested that the oxides could be arranged in the order of their increasing basicity according to this definition. The normal oxides present in acid open hearth slags may be arranged according to their increasing basicity as SiO_2, Al_2O_3, MnO, FeO, and CaO.

According to the Lewis theory, the more basic oxides such as those of iron, manganese, and lime would furnish the oxide ion $(O)^{2-}$ concentration of a slag thereby making available an electron pair to any acidic molecular species.

Huggins and Sun[16] suggested that the addition of the oxide ion to silica would change its acidity in progressive steps as shown in Table I.

According to this progressive series of silicate ions, the function of the basic oxides such as FeO, MnO, and CaO is to furnish the oxygen ion and its available electrons for bonding with the silicon to make a more basic molecular species. With more iron oxide (or MnO and CaO) more of the oxide ion $(O)^{2-}$ would be made available to the slag in increasing steps as follows:

$$2SiO_2 + (O)^{2-} \rightarrow (Si_2O_5)^{2-} \quad [1]$$

$$(Si_2O_5)^{2-} + (O)^{2-} \rightarrow 2(SiO_3)^{2-} \quad [2]$$

$$2(SiO_3)^{2-} + (O)^{2-} \rightarrow (Si_2O_7)^{6-} \quad [3]$$

$$(SiO_3)^{2-} + (O)^{2-} \rightarrow (SiO_4)^{4-} \quad [4]$$

Ionic Theories and Acid Open Hearth Refining

In Fig. 9 it was shown that the SiO_2 contents of acid open hearth slags normally vary from 43 to 58 pct. Assuming that the remaining constituents were only FeO and MnO, then the molecular ratios of $(FeO + MnO)/SiO_2$ vary from 0.60 to 1.11. Such a range in composition might suggest that the predominant silicate ions which normally exist in such slags would be $(Si_2O_5)^{2-}$ and $(SiO_3)^{2-}$ according to the progressive series of ions suggested by Huggins and Sun.[16] For the purposes of the discussion which follows, it will be suggested that both these and the oxygen ion exist simultaneously, together with the positively charged metallic ions. Possibly even a balance is assumed in the relationships of these ions according to the relation

$$2(SiO_3)^{2-} \rightleftarrows (Si_2O_5)^{2-} + (O)^{2-} \quad [5]$$

or the reverse of Eq. 2, with the understanding that the Fe^{2+} and Mn^{2+} ions are always present.

Oxidation of the Metal Due to a Temperature Increase: It was shown in the discussion of the phase diagram in Fig. 10 that apparently oxygen is released to the metal bath simply by means of a rapid increase in temperature. Inasmuch as less of the basic oxide is needed to saturate silica with increasing temperature, it might be assumed that the $(Si_2O_5)^{2-}$ ion is favored over the $(SiO_3)^{2-}$ ion at higher temperatures. Thus, the tendency would be for some of the $(SiO_3)^{2-}$ ion to release some of its oxygen as the temperature is increased and in accordance with the trend of Eq. 5.

Both excess oxygen and iron (or manganese) ions would be available for distribution to the metal bath. The oxygen would be furnished for carbon elimination and the iron simply becomes a part of the metal bath.

The chief advance in thought to be obtained from the ionic theory is that all of the basic oxides FeO, MnO, and CaO apparently serve the same function in furnishing the basic oxide ion $(O)^{2-}$ to the SiO_2 to form the silicate ions, $(Si_2O_5)^{2-}$ and $(SiO_3)^{2-}$. Because FeO and MnO have nearly the same relative bond or basic strength according to Sun,[15] the iron furnishes the additional oxygen if it is in excess of the MnO and the reverse becomes true in high MnO slags. That this is true is possibly indicated by the fact that in the latter slags the manganese content of the bath increases during the carbon boil.

SiO_2 Precipitation Due to a Temperature Decrease: The carbon reaction in an acid open hearth furnace may be caused to cease by either holding the temperature constant or permitting it to reduce slightly. According to the phase diagram concept holding the temperature would cause the slag to approach saturation with respect to SiO_2 (line *BC*) and to precipitate SiO_2 with a reduction in temperature (line *CD*). If it is assumed again that the $(Si_2O_5)^{2-}$ ion is favored by an increased temperature, then it might conceivably be less stable with a reduction in temperature so that some solid silica would precipitate.

$$(Si_2O_5)^{2-} \rightarrow SiO_2 \text{ (solid)} + (SiO_3)^{2-}.$$

This would conform with the phase diagram concept because on cooling the newly formed silica would tend to be in equilibrium with a liquid containing more oxygen at the lower temperature. However, this oxygen is not available for reaction in the metal phase. Instead, it is associated with the silicon in the higher oxygen complex, i.e., $(SiO_4)^{4-}$.

Table I. Types of Silicate Ions as Determined by Presence of Basic Oxides

	Acid	Decreasing Acidity			Basic
Acidity	SiO_2	$(Si_2O_5)^{2-}$	$(SiO_3)^{2-}$	$(Si_2O_7)^{6-}$	$(SiO_4)^{4-}$
Atoms of O per atoms of Si	2	2.5	3	3.5	4
Molecule basic oxide to molecule SiO_2	0	0.5	1	1.5	2.0

Transfer of Oxygen from the Flame to the Metal Bath: The acid slag is, of course, in direct contact with iron, but in addition some metal particles are forced through the slag and in direct contact with the flame because of the carbon boil. As described previously[2] the metal particles might be responsible for much of the transfer of oxygen from the flame to the metal because the slag contains as much as one or two per cent of metal particles during the boil. The oxidation of these particles and their subsequent contact with the slag and/or metal cause the continued elimination of the carbon.

As far as the slag phase is concerned, the oxidation of these particles would result in the formation of more oxide ion $(O)^{2-}$ and the formation of the higher oxygen silicate ion just as would an ore addition.

Role of Cr_2O_3 and/or Al_2O_3: The presence of several per cent of Cr_2O_3 or Al_2O_3 in the slag is apparent to the open hearth operator. If either oxide is present in quantities up to 5 pct or above, a noticeable decrease in oxidizing power of the slag results. As stated previously, these are the only oxides which can be detected in acid open hearth slags by either petrographic or X-ray methods. A strong tendency exists for these oxides to form spinels, i.e., $(FeO)_3Al_2O_3$ or $(FeO)_2Cr_2O_3$. The effect of such spinel formations on the oxidizing power of the slags is obvious. Further, it is likely that some ions are formed by the amphoteric oxides and that these might be $(AlO_3)^{3-}$ and $(CrO_3)^{3-}$. However, because of their weak acidic nature but their strong tendency to form the high melting spinels, the latter crystallize readily and remove some of the oxide ion from its combination with the silicate ions or for oxidation of the metal bath.

It is known that high temperatures tend to break up these spinels and in the case of the chromium, it is reduced into the metal bath under such conditions. Thus, the ionic theory also aids in understanding the effects of spinels in acid slags.

Summary

Some operational phenomena that have been observed to occur in the refining of steels in the acid open hearth furnace have been described. It has been indicated that the refining process may be controlled within practical limits through the use of certain phase diagram considerations involving the slag constituents.

Some additional information was given to show that iron oxide and manganese oxide apparently reverse their respective trends depending upon the concentration of each present in the slag. If the percentage of manganese oxide is less than 25 pct (as in American practice), the concentration of manganese oxide will remain essentially constant throughout the heat. In this case, the iron oxide will decrease in concentration and apparently is responsible for the elimination of carbon under these conditions.

If, on the other hand, the manganese oxide content is increased to as much as 30 to 35 pct in the slag, the iron and manganese oxides reverse their trends. In this case the iron oxide content remains constant and the manganese oxide apparently furnishes the oxygen for the carbon removal. Simultaneously, a manganese increase in the metal bath is to be observed.

The phase diagram concept mentioned above does not adequately answer all the questions which arise in view of these phenomena and certain ionic theories of slags were considered in the hope of answering some of the questions.

It was concluded that acid open hearth slags probably contain at least two silicate ions, i.e., $(Si_2O_5)^{2-}$ and $(SiO_3)^{2-}$. The oxygen(or oxide) ion $(O)^{2-}$ as well as the positive ions of iron and manganese also probably exist in these slags at all times.

The addition of manganese and lime oxides to such a slag merely increases the oxide ion because these oxides apparently ionize and furnish more oxide ion, either for reaction with the constituents in the metal bath, or for the formation of a silicate ion containing more oxygen. The basic oxides are, therefore, additive in their supply of the oxygen ion and this additive nature was not previously explained by the phase diagram considerations.

If the MnO content exceeds 25 pct, it apparently furnishes the excess oxide ion for carbon elimination instead of the iron oxide which in this case is much lower in concentration. This is shown by the fact that such slags furnish oxygen for the metal bath simultaneously while a manganese reversion takes place.

It has been suggested that the $(Si_2O_5)^{2-}$ ion is benefited by an increase in temperature so that merely raising the temperature will cause the $(SiO_3)^{2-}$ ion to furnish the free oxide ion $(O)^{2-}$ and some $(Si_2O_5)^{2-}$, thus increasing carbon elimination. This is in line with the phase diagram concept.

The presence of appreciable amounts of Al_2O_3 and/or Cr_2O_3 apparently will reduce the oxidizing characteristic of acid slags by combining with the oxide ion to form a complex ion such as $(Cr_2O_5)^{4-}$ and ultimately stable solid compounds, i.e., the spinels.

In general, the ionic theories strengthen the phase diagram explanations and add to the science, particularly in suggesting the idea that basic oxides furnish the oxide ion $(O)^{2-}$ to acid slags and that their effects are additive.

References

[1] G. R. Fitterer et al.: Acid Open Hearth Slag Fluidity and Its Significance. *Bulletin No. 1*, Acid Open Hearth Research Association, Inc., Pittsburgh (1945).

[2] G. R. Fitterer: *Trans.* ASM (1945) **34**, p. 1.

[3] P. Herasymenko: *Journal* Iron and Steel Inst. (1947) **157**, p. 515.

[4] C. A. Bruch: Oxidizing Characteristics of Acid Open Hearth Slags. Ph.D. Thesis, 1952. Univ. of Pittsburgh.

[5] G. R. Fitterer: *Proc.* Electric Furnace Steel Committee, AIME (1946) **4**, pp. 185-198.

[6] C. H. Herty, Jr. and G. R. Fitterer: *Industrial and Engineering Chemistry* (1929) **21**, No. 1, p. 51.

[7] N. L. Bowen and J. F. Schairer: *American Journal of Science* (1932) 5th Ser., **24**, p. 200.

[8] Charles R. Funk and Kenneth Midlam: *Proc.* National Open Hearth Conference, AIME (1950) **33**, p. 292.

[9] J. W. Linhart and Nezih Rona: The System $(FeO)_2SiO_2$-$(MnO)_2SiO_2$. M.S. Thesis, Metallurgical Engineering, Univ. Pittsburgh, 1945.

[10] C. Doelter: *Sitzungsbir Wien Akad. Wissensch.* (1907) **116**, p. 1249.

[11] P. Herasymenko: *Trans.* Faraday Soc. (1938) **34**, p. 1245.

[12] J. Chipman and Lo-Chang Chang: *Trans.* AIME (1949) **185**, p. 191; JOURNAL OF METALS (February 1949).

[13] G. N. Lewis: *Journal* Franklin Inst. (1938) **226**, p. 293.

[14] K. H. Sun and A. Silverman: *Journal* Amer. Ceramic Soc. (1945) **28**, p. 8.

[15] K. H. Sun: *The Glass Industry* (1948) **29**, p. 73.

[16] M. L. Huggins and K. H. Sun: *Journal of Physical Chemistry* (1946) **50**, p. 319; (1947) **51**, p. 438.

Solid Phase Identification in Partially Reduced Iron Ore

by Gust Bitsianes and T. L. Joseph

THE reduction of a lump of iron ore is a complicated sequence of up to three reactions proceeding simultaneously in a gas-solid system. As the ore moves down the blast furnace into zones of higher temperature and higher reducing power, it is successively reduced through the three oxides of iron into metallic iron. The reduction process involves much more than chemical problems. Physical factors add to the complexity of the overall process.

Under optimum conditions, reduction of the ore is completed at a level about one-half way down the blast furnace stock column. At this point, the ore undergoing reduction has attained a temperature of about 1000°C and has been in the furnace for about 6 hr. On the practical side, the behavior of the ore during smelting has been of great interest to operators. Unsatisfactory blast furnace operation on burdens containing magnetite ore or badly slagged sinter has often been attributed to poor reducibility. The question of reducibility has also been raised in formulating quality standards for agglomerates such as nodules, briquettes, and pellets. In the present investigation, the solid phases formed during reduction were studied as a step toward a better understanding of the overall process.

Equilibrium Studies

The iron-oxygen equilibrium diagram shown in Fig. 1 reveals a number of facts pertinent to the gaseous reduction of iron ores. This diagram is from the work of Darken and Gurry[1, 2] and represents a correlation of the best available data. Four solid phases may exist during the complete reduction of hematite to metallic iron. These are hematite (Fe_2O_3), magnetite (Fe_3O_4), wüstite (FeO_x), and iron (Fe). The wüstite phase is a solid solution which is not stable below 570°C. At this temperature the solid solution undergoes a eutectoid-type of decomposition into the phases, magnetite and iron. Thus above 570°C, the diagram dictates that a hematitic ore should pass through a four-phase sequence on reduction to metallic iron. Below 570°C, only hematite, magnetite, and iron should appear.

Information on the iron-oxygen system has been derived largely from CO and H_2 reduction equilibria. The Fe-C-O relationships have been studied extensively by R. Schenck and his coworkers and well summarized by H. Schenck.[3] More recent studies have been made by Darken and Gurry.[1, 2] Data from these sources have been combined and plotted in Fig. 2. With respect to the Fe-H-O system, the works of Emmett and Schultz[4] seem the most reliable, and these data have also been included in Fig. 2.

G. BITSIANES and T. L. JOSEPH, Members AIME, are Assistant Professor and Professor of Metallurgy, respectively, Minnesota School of Mines and Metallurgy, Minneapolis.

Discussion on this paper, TP 3659C, may be sent, two copies, to AIME by April 1, 1954. Manuscript, July 2, 1953. New York Meeting, February 1954.

This paper is based on a thesis by G. Bitsianes submitted in partial fulfillment of requirements for the degree of Doctor of Philosophy to the University of Minnesota, August 1951.

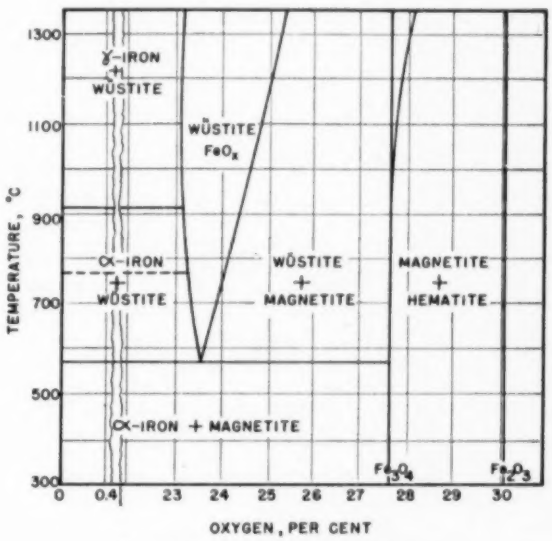


Fig. 1—Iron-oxygen equilibrium diagram.

Certain physical properties of the solid phases of the iron-oxygen system are summarized in Table I. The crystallographic information is of special interest as much of the present work has been concerned with the X-ray analysis of the products of reduction.

Reduction with Hydrogen

The reduction of ore with hydrogen is the net result of two or more gas-solid reactions. Above 570°C, the reaction sequence may be represented by stoichiometric stages as follows:

$$3Fe_2O_3 + H_2 \rightleftharpoons 2Fe_3O_4 + H_2O \quad [1]$$

$$2Fe_3O_4 + 2H_2 \rightleftharpoons 6FeO_{(x)} + 2H_2O \quad [2]$$

$$6FeO_{(x)} + 6H_2 \rightleftharpoons 6Fe + 6H_2O \quad [3]$$

$$Fe_2O_3 + 3H_2 \rightleftharpoons 2Fe + 3H_2O. \quad [4]$$

These reduction reactions follow the general form:

$$A \text{ (solid)} + B \text{ (gas)} \rightleftharpoons C \text{ (solid)} + D \text{ (gas)}.$$

This type of gas-solid reaction has been investigated by Langmuir[11] who has shown that such reactions can occur only at the boundary between the two solid phases. Furthermore, a nucleus of the second phase must initiate the reaction. Once such an interface exists, the reaction proceeds through a layer of the solid reaction product (C). The specific mechanisms involved will depend a great deal on the properties and condition of this particular layer. A number of heterogeneous reactions such as the dehydration of single crystals of copper pentahydrate and the calcination of limestone follow this type of process. It should be noted that the interfacial type of reaction also occurs even in dense polycrystalline material which simulates a monocrystalline behavior.

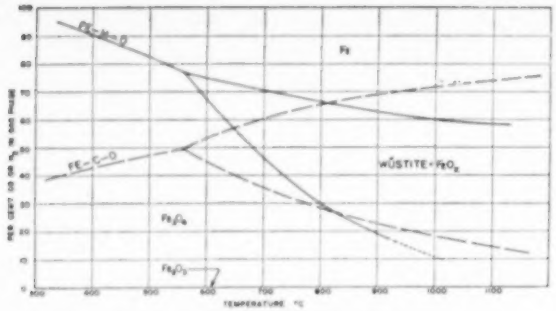


Fig. 2—Fe-C-O and Fe-H-O reduction equilibria.

Of further interest is the propagation of many of these reactions in such a way that the interface maintains a position parallel to the crystal face from which it originated. Advance of the interface is governed by rate-controlling factors and the geometry of the crystal. Sectioning of such a partially reacted specimen will often reveal an unaltered center which follows the contour of the original crystal. This behavior is especially characteristic of many heterogeneous reactions involving a gaseous phase. Solid state reactions which follow this behavior are a special type of what Kohlschütter[12] called "topochemical" reactions a long time ago. This designation will be used hereafter whenever a description of the basic process is necessary.

It has often been surmised that a lump of hematite is reduced successively through the oxides of iron in such a fashion that the phases are formed in a definite layered pattern. Of the many authors who have investigated this aspect of reduction, whether intentionally or not, only a few will be mentioned. Kalling and Lilljequist,[13] Wienert,[14] Baukloh and Froeschmann,[15] Kalina and Joseph,[16] and Chufarov and Tatievskaya[17] have shown that reduction reactions tend to follow a topochemical path.

The reduction process is not a simple case of topochemistry but involves a series of such reactions. Multilayered structures in partially reduced products have been observed by many investigators so that this concept is not new. The clearest idea of the overall behavior may be gained by considering that the reduction of each oxide layer proceeds in a topochemical fashion of its own so that the spacing of the various interfaces is mainly a function of specific rate factors. The number of such interfaces is in turn a function of the number of phases involved in the overall process. There has been, however, a difference of opinion as to the number of phases that may exist. The simplest approach is to assume that the number of phases and their relationships are fixed by the equilibrium requirements of the iron-oxygen system. Whether the equilibrium relationships, determined for specific conditions, dictate the manner in which a lump of iron ore is dynamically reduced, has been questioned.

Hofmann[18] has claimed that the wüstite phase can form at any temperature above or below the quadruple point of 570°C and that in the same range of temperature, magnetite need not be a primary reduction product. Wienert[14] reported wüstite or a "ferrophase" in products at 540°C. After using special kinetic measurements, Olmer[19, 20] concluded that hematite is reduced directly to metallic iron above 325°C. Taylor and Starkweather[21] reported a similar conclusion but at a temperature of 450°C. Most of these controversial results have been derived from simple rate measurements which are not sufficient to analyze the reduction process. A number of investigators[17, 22-24] have attempted to identify the solid phases of reduction by means of metallographic or X-ray methods of analysis. Their results have been largely inconclusive because of the experimental difficulties encountered. Wiberg's work[22] is an exceptional case. He obtained excellent micrographs of partially reduced Kiruna magnetite which showed the layered structure that would be expected from reduction equilibria.

Experimental Procedure

In early work the authors, like many previous investigators, attempted a study of the reduction process by an evaluation of rate data obtained under a variety of conditions. It soon became apparent, however, that a more direct approach was needed. The method finally adopted was that of quenching the specimen to "freeze" it at a certain reaction point, sectioning it to reveal its inner strata, and then investigating the section with all the available means. This method proved to be highly effective.

Carbon monoxide is the major reductant of industrial operations but it undergoes certain side reactions which complicate the reduction process and the identification of solid phases in partially reduced specimens. Purified cylinder hydrogen is convenient to use and is stable over the temperature range of interest. There are undoubtedly some differences in the behavior of hydrogen and carbon monoxide molecules during the reduction sequence but the general type of reaction should be much the same.

Selection of Iron Ore: Iron ores behave very differently during reduction. Some ores crack under

Table I. Physical Properties of Iron and Its Oxides at 20°C.[5-10]

Name and Formula	Molecular or Atomic Weight	Fe, Pct	Density, Gram per Cc	Crystallographic Data: System and Structure	Space Group: Schoenflies	a,A	c,A	Axial Angle	Mols per Unit Cell
Iron									2
α Fe	55.85	100.0	7.874	bcc, W	O_h^9	2.8664			4
γ Fe	55.85	100.0	8.145 cal.	fcc, Cu	O_h^5	3.571 extrap.			4
Wüstite,* FeO	73.07	76.43	5.645	fcc, NaCl type	O_h^5	4.300			
Magnetite, Fe_3O_4	231.55	72.36	5.175	cubic, $MgAl_2O_4$ type	O_h^7	8.391			8
Hematite									
α Fe_2O_3	159.70	69.94	5.260	hexag. or rhomb.	D_{3d}^6	5.039 5.426	13.76	55°17'	6 2
γ Fe_2O_3	159.70	69.94	4.898 cal.	cubic, $MgAl_2O_4$ type	O_h^7	8.33			10 2/3

* As wüstite is a solid solution, the physical properties for the phase are given only for the eutectoid composition at 76.43 pct Fe.

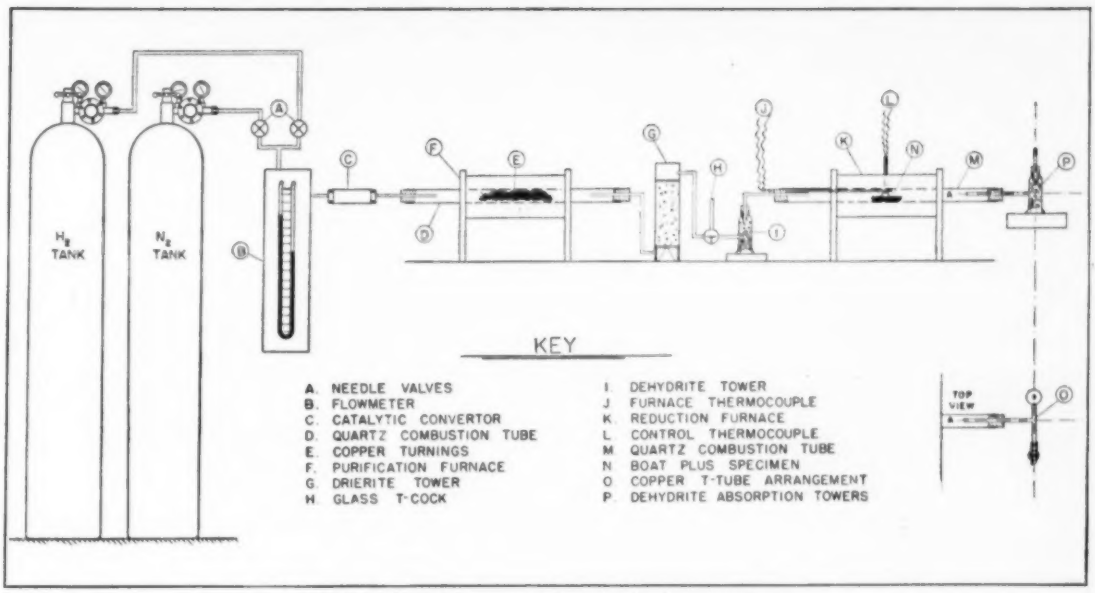


Fig. 3—Schematic representation of reduction apparatus.

the influence of heat alone. Others crack at various stages of reduction. Physical or chemical discontinuities tend to obscure phase relationships in partially reduced specimens. For the best results in studying the solid phases formed during reduction, an ore should possess the following properties: 1—The ore must be a hematite. Magnetites are too individualistic in their behavior. 2—The ore must be dense with a porosity of 10 pct or less. 3—The ore must be homogeneous with an even dispersion of pores and finely divided impurities. 4—The ore must be relatively pure to avoid cracking and the effect of complicated side reactions.

In view of these requirements, a dense ore from the Vermillion Range in Minnesota designated as 8B was chosen for much of the work. It contained 65 pct iron, about 7 pct silica, and was physically homogeneous with an even distribution of the 3 pct of pore space. Pieces of the ore resisted thermal spalling and reduced without excessive shrinkage or cracking.

Compacts of finely divided pure hematite offer certain advantages in a study of the reduction process. Moreover, work on such compacts affords an insight into some of the problems associated with the agglomeration of fine concentrates or fine iron ore. This aspect of the reduction field was extensively studied and the results will be reported later.

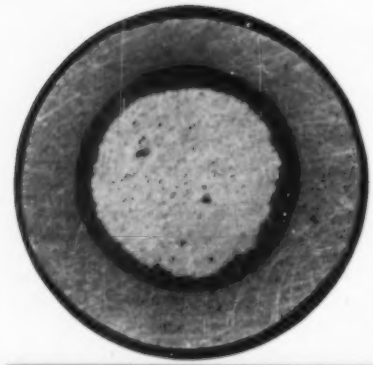
Reduction Apparatus: The apparatus used in the preparation of partially reduced specimens is shown schematically in Fig. 3. By automatic control of the electrical resistance furnace, the temperature of the specimen could be held to within ±1°C. The reduction reactions were carried out in a quartz combustion tube of 1 in. ID. All specimens were held in a nichrome-screen boat which could be immediately withdrawn into a water-cooled "quenching" chamber attached to the end of the reaction tube. The remaining part of the apparatus was needed to supply and purify tank hydrogen and nitrogen at controlled rates.

Nitrogen was passed over the specimen for 15 min while it was slowly brought up to the desired temperature. With the system in an isothermal state, hydrogen was passed over the specimen at the rate of 1200 ml (standard temperature and pressure) per min. At the end of a run, the specimen was withdrawn into the quenching chamber where it cooled rapidly in an atmosphere of hydrogen. This moderate cooling rate was found to be fast enough to "quench" the reduction reactions without any cracking effects which could be detrimental to the later operations.

Examination of Partially Reduced Specimens: Most of the partially reduced specimens were too friable to be handled freely. It was not only necessary to strengthen the structure but also to fill in the cracks and pores characteristic of reduced material. After unsatisfactory results with many agents and techniques, impregnation with liquid organic monomers afforded a satisfactory solution to the problem. These liquids could be readily set by the simple process of polymerization. Either methyl methacrylate monomer, which polymerizes into Lucite, or styrene monomer, which polymerizes into polystyrene, was found to be satisfactory. Specimens were covered and impregnated with the prepared monomer using a conventional vacuum technique. Polymerization was then induced under a definite time-temperature schedule which required about three days at 45°C for the methyl methacrylate monomer. After cooling, the mass of polymer could be sectioned at will to reveal the strata of the partially reduced ore.

Macroexamination: Impregnated half-sections were mounted in bakelite and then ground on a glass plate with wetted carborundum powders. This rough surfacing was followed by a wet finish on special grades of abrasive paper (Wetordry). The latter had been found to give the clearest resolution of the reduction strata in macro form. In many cases the reduction strata were clearly visible to the eye and could be macrophotographed at magnifications of 3 to 5 diameters. These macrophotographs were valuable in directing the more searching techniques which were to follow.

Microexamination: The preparation of a highly polished surface on partially reduced iron ore was not a simple operation. A typical cross section in this work contained as many as four different



a (left)—Synthetic ore pellet. Partially reduced in hydrogen at 750°C for 40 min. Etched.

b (below)—Natural dense ore 8A. Half section of rectangular prism. Partially reduced in hydrogen at 850°C for 35 min. Etched.

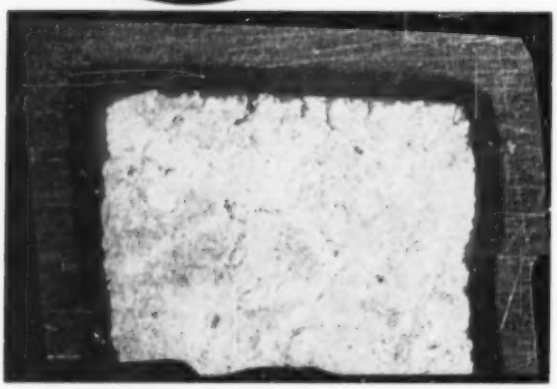


Fig. 4—Topochemical aspects of dense ore reduction. X4.5. Area reduced approximately 30 pct for reproduction.

phases. The outer layer was normally one of soft metallic iron which surrounded an inner cored structure of up to three oxide phases of a varying mineralogical nature. Water-suspended abrasives held on a cloth or fabric of suitable texture were not satisfactory in polishing this type of material. When working with minerals, it is well known that the best polishing action is obtained with specialized techniques which involve the use of abrasives embedded on laps of relatively soft material. The Graton-Vanderwilt polishing machine which is based on this principle was used throughout this investigation. A special procedure was developed for the handling of partially reduced ore structures.

The specimens were polished on a sequence of cast iron and lead laps, each of which was charged with a diminishing size of emery abrasive. A lubricant of kerosene and oil was used and the best polishing action occurred when the laps were running in the relatively "dry" state. After attaining a suitable polish, the specimens were microexamined using conventional metallographic techniques. Micrographs were taken and the magnifications required for the proper resolution of detail were on the order of 500 diameters. It was found that there was normally enough phase contrast in the polished sections so that the various phases could be clearly differentiated. The one exception was that of the wüstite-magnetite combination in which no such differentiation existed. It was necessary to darken the wüstite with a 2 pct acidified solution of stannous chloride to produce a clear-cut boundary between the two phases.

X-Ray Analysis: Positive identification of some of the phases in partly reduced iron ore demanded a method more precise and reliable than microscopic examination. For these requirements the powder method of X-ray analysis seemed most logical. After cutting a thin slice from the center of the impregnated block specimen, its corners were removed so that the strata were exposed in true layer fashion. Starting at the exterior surface, successive layers were filed off to yield representative powder samples for each 0.5 mm of file penetration. A typical sampling operation is shown in Fig. 5. Each series of samples was then X-rayed on a Picker's diffraction unit using unfiltered radiation from an iron target tube.

For the actual powder analyses a Picker's camera, 214.86 mm in diameter, was used and the powdered samples were held in collodion tubes 0.4 mm in diameter. The large patterns thus obtained were valuable in calculating accurate lattice parameters as well as in resolving structures containing two or more phases. During a run the X-ray tube was operated at 35 kv and with a filament current of 10 milliamperes. Under these conditions 5 hr were necessary to produce acceptable patterns.

It was necessary to have proper phase standards in order to use the X-ray data for solid phase identification. Electrolytic iron was chosen for iron, and material prepared from ore 8B was used in producing a standard X-ray pattern for wüstite. Crystalline magnetite from New York and crystalline hematite from Elba were used to obtain standards for these two oxides. The resulting patterns were measured and the crystallographic constants calculated from Bragg's law. A comparison of these values with those from the literature is given in Table II.

The selection of a standard reference for the wüstite phase presented some difficulties as this material does not exist in nature. As only a few milligrams were required, a rather simple method for its preparation was devised. When a dense hematite ore (8B) was partially reduced at above 570°C, a definite layered structure was formed. On X-raying the separate layers, it was found that the second of these gave a diffraction pattern different from that of iron, magnetite, or hematite. The diffraction lines of this unidentified phase were broad and diffuse and the doublets in the high θ region were entirely obscured. This condition could be attributed to the variable composition of the wüstite layer resulting from partial reduction. After annealing and homogenizing for 20 hr at 700°C, an excellent pattern was produced for standardization purposes. The pattern as evidenced in Fig. 6 had sharp lines throughout and its doublets were clearly resolvable. The agreement of d_o values and unit parameter with standard values reported in the literature positively identified the material as the wüstite phase.

Experimental Results

Topochemical Aspects of Dense Ore Reduction: The tendency of reduction to follow a topochemical path was observed early in this investigation. That is, under normal conditions, the phases were orientated in a definite layered pattern with the interfaces following the original contour of the specimen.

Table II. Parameter Data for the X-Ray Standards

		Accepted Values		Experimental Values	
Phase	System	a_o (A)	Alpha	a_o (A)	Alpha
Iron	Cubic	2.8664		2.866(9)	
Wüstite	Cubic	4.300 (eut.)		4.303(2)	(Layer average)
Magnetite	Cubic	8.391		8.396(3)	
Hematite	Rhomb.	5.426	55°17'	5.42(6)	55°16'

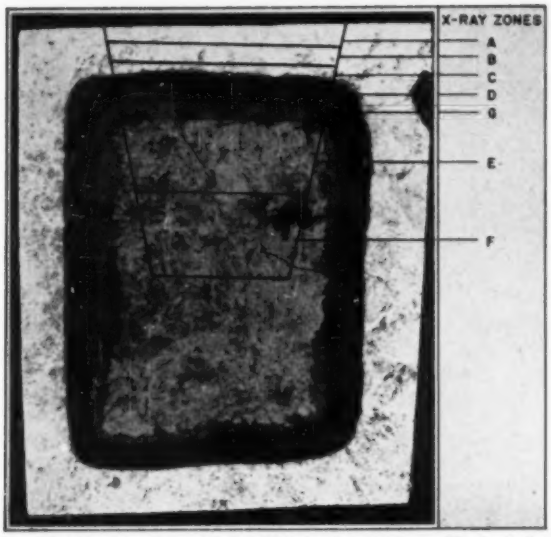


Fig. 5—Macrostructure of natural dense hematite, ore 8B. Partially reduced in hydrogen at 850°C for 35 min. Etched. X7. Area reduced approximately 70 pct for reproduction.

These interfaces were more apparent for certain types of ore and particularly at temperatures above 570°C. The topochemical behavior of dense hematitic ore is shown in Fig. 4. Two sections are illustrated; one for the standard dense hematite and one for a synthetic pellet. Close inspection of the macrographs reveals that the ore structures had apparently gone through the same fundamental mechanisms. A layered arrangement of four solid phases was evident and these were differentiated clearly by three reduction interfaces. The reacting interfaces were evenly spaced in topochemical fashion with respect to the boundaries of the original specimens.

Reduction of Dense Hematite Ore Above 570°C: The topochemical behavior of dense hematite ore was studied more extensively. For this study, a block specimen of ore 8B was partially reduced at 850°C and the resulting cross section is shown in Fig. 5. Some information about the four reduction phases may be gained from a simple macroexamination. For instance, it was immediately apparent that the center was unreduced and therefore representative of the starting material. The outer layer contained grinding scratches and presented a brilliant metallic luster, both typical of metallic iron. Identification of the two intermediate phases was less positive. The outer one of these two layers tended to darken perceptibly on etching with the stannous chloride reagent. This behavior suggested that the material was wüstite as magnetite is notably inert to such mild etching treatment. In later operations the inner layer tended to polish more readily. This action suggested that the material was magnetite as that particular phase has a good polishing reputation in the iron oxide family. The macroexamination technique was thus instrumental in providing a rough identification of the phases of reduction.

A more positive means of identification is that of X-ray analysis. Accordingly, seven separate layers were filed from the surface to the center of the specimen as indicated in Fig. 5. The X-ray patterns from the series of powder samples are presented in Fig. 6. To facilitate identification, the standard patterns for iron and its oxides have been inserted in the series at the appropriate positions for a comparative type of analysis. It is immediately apparent that the outermost layers *A* and *B* were metallic iron. The patterns obtained were broad-lined and diffuse because of the cold-worked nature of the iron particles. No attempt was made to anneal the powders of this particular series as the identification was positive enough without this treatment.

As shown by the X-ray evidence, layer *C*, which was located at the first reaction interface, contained both iron and wüstite. Proceeding deeper into the specimen, layer *D* was found to be composed entirely of the wüstite phase. The phase was a soft, black and easily powdered material of variable composition as indicated by the diffuseness of its X-ray pattern. Actually this same material had been used earlier in the preparation and study of the wüstite phase standard.

The next layer *G* was composed almost entirely of magnetite. As this layer was less than 0.5 mm thick, it was difficult not to include some of the wüstite phase in the sample. Beyond layer *G*, the material was not susceptible to filing. Block specimens were cut out and pulverized to obtain powdered samples from the unreduced core. The X-ray patterns of layers *E* and *F* correlate well with the macrograph in showing that the core was unreduced hematite corresponding with the original ore.

A microscopic study of the polished specimen revealed some additional information on the conditions at each of the reduction interfaces. Fig. 7a shows the iron-wüstite interface at 500 diameters. The iron was white and had a brilliant metallic luster. It had the typical appearance of newly formed sponge iron of relatively small grain size, and there was evidence that only a small amount of sintering had taken place. The wüstite phase in this particular section contained a large amount of interlocked silica from the original ore and had been etched to the color shown. It appears that the silica had no profound effect on the reduction of the wüstite phase. At this magnification the actual reduction interface was not a narrow one but represented a reaction zone on the order of 25 to 30 microns in width. This width was found to vary in general with the porosity of the phases undergoing reduction. The series of micrographs substantiates this finding by showing that the succeeding interfaces

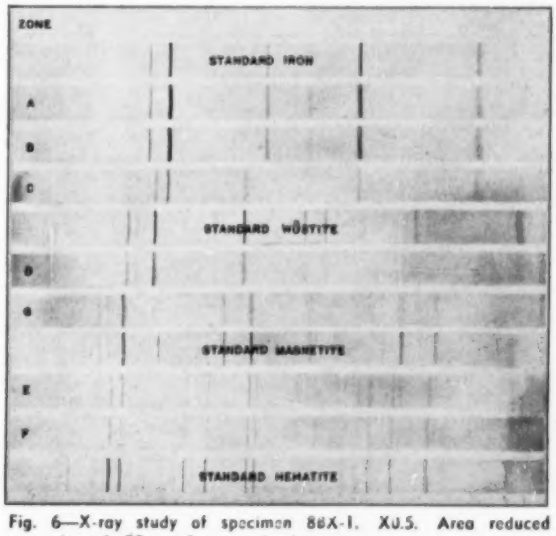
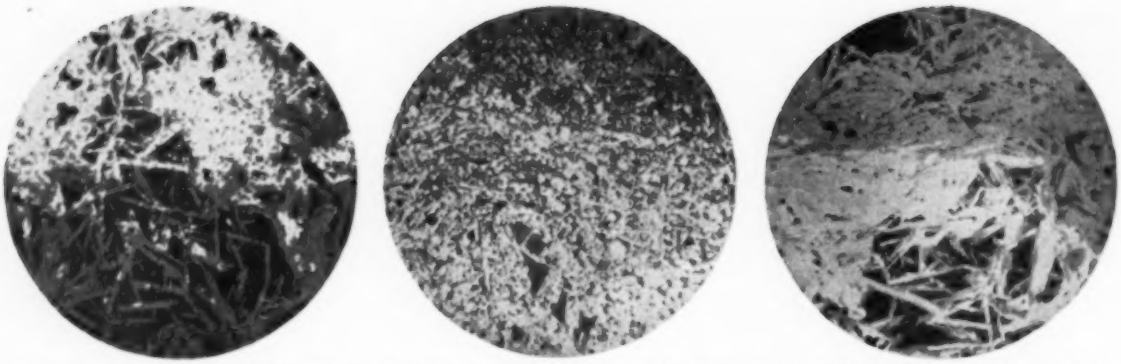


Fig. 6—X-ray study of specimen 88X-1. XU.S. Area reduced approximately 75 pct for reproduction.



a—Iron-wustite interface. White phase, iron; dark gray phase, wustite; black inclusions, silica.

b—Wustite-magnetite interface. Dark gray phase, wustite; light gray phase, magnetite.

c—Magnetite-hematite interface. Light gray phase, magnetite; light phase, hematite; black inclusions, silica.

Fig. 7—Reduction interfaces of natural ore 8B. Reduced in hydrogen at 850°C for 35 min. Etched. X500. Area reduced approximately 30 pct for reproduction.

were progressively narrower than the one under discussion. The idea that the reaction zone may have a definite width can be explained on the basis of variations in physical structure or in chemical activity of the phases concerned. Due to unevenness in porosity, the hydrogen has a greater access to certain crystalline aggregates. From the chemical point of view, some of the wüstite grains may be more reactive than others thus giving width to the reaction zone.

The wüstite-magnetite interface shown in Fig. 7b could not be differentiated in the polished condition without the proper etching to darken the wüstite layer. Again the interface had a finite width for the reasons given. There was little evidence of any proeutectoid precipitation of magnetite from the wüstite phase. Finally the magnetite-hematite interface is shown in Fig. 7c. This interface had narrowed considerably and followed a jagged contour in keeping with the acicular nature of the hematite undergoing attack.

Only the interfacial relations have been discussed here. A careful study across the polished layers confirmed the belief that these were generally homogeneous and of a single-phase constitution.

Reduction of Dense Hematite Below 570°C: For a study of the phases formed during reduction below 570°C, a 1 cm cube of hematite ore (8B) was partially reduced at 500°C and quenched in the manner previously described. As shown by the macrograph in Fig. 8a, the course of reduction differed from that followed at 850°C. The white outer layer had all the characteristics of sponge iron and appeared to have formed in a rough topochemical fashion. The reduction of the interior, however, was accompanied by a great deal of cracking despite the low temperature employed. Cracking promoted the formation of magnetite along paths of least resistance into the

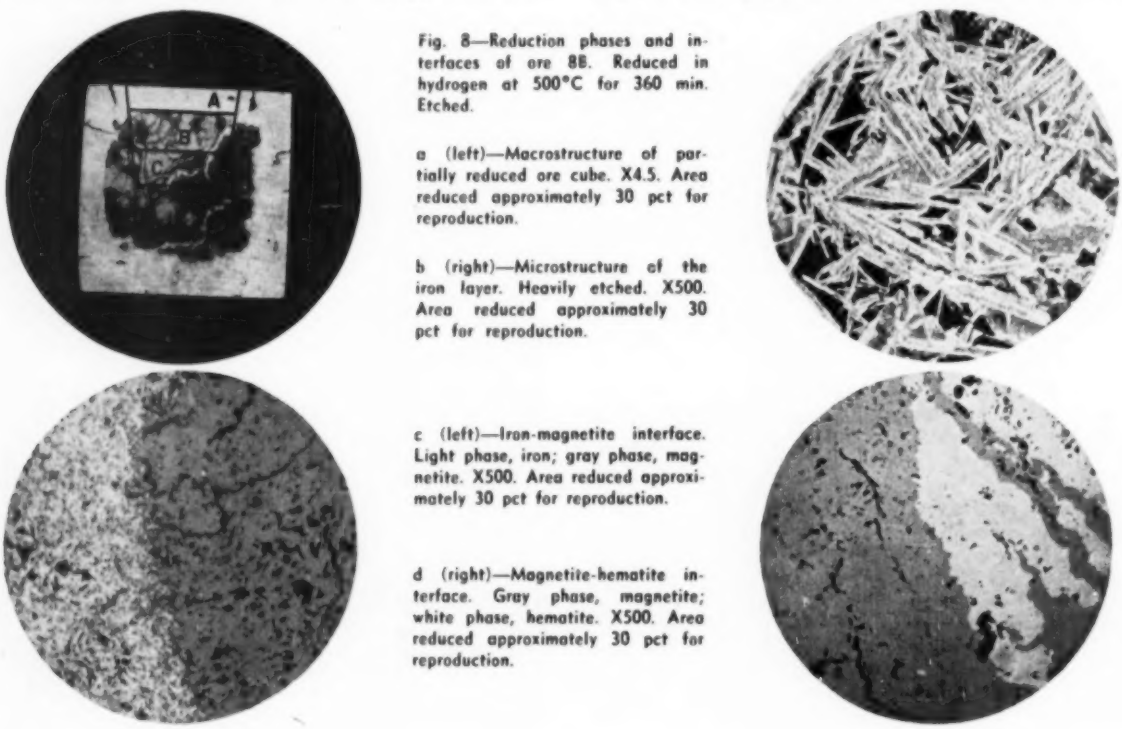


Fig. 8—Reduction phases and interfaces of ore 8B. Reduced in hydrogen at 500°C for 360 min. Etched.

a (left)—Macrostructure of partially reduced ore cube. X4.5. Area reduced approximately 30 pct for reproduction.

b (right)—Microstructure of the iron layer. Heavily etched. X500. Area reduced approximately 30 pct for reproduction.

c (left)—Iron-magnetite interface. Light phase, iron; gray phase, magnetite. X500. Area reduced approximately 30 pct for reproduction.

d (right)—Magnetite-hematite interface. Gray phase, magnetite; white phase, hematite. X500. Area reduced approximately 30 pct for reproduction.

light gray areas of unreduced hematite. These conclusions were verified by X-ray analysis of samples removed from positions as shown on the macrograph. The results obtained were as follows: layer *A*—iron (very strong pattern); layer *B*—iron (medium), magnetite (very strong); and layer *C*—magnetite (very strong), hematite (medium).

The X-ray studies were supplemented with micrographs also shown in Fig. 8. A section of the iron layer which had been heavily etched to bring out a peculiar grain structure is shown in Fig. 8b. This needle-like structure was strongly pseudomorphic after certain areas of the original hematite. It was not characteristic of the entire layer of iron but only of those sections carrying a high concentration of interlocked silica inclusions.

The iron-magnetite interface is visible in Fig. 8c. The iron was fine-grained and made a narrow, sharply defined interface with the magnetite phase. This condition was in direct contrast with the wider interfaces formed with wüstite at temperatures above 570°C. A careful inspection of the magnetite phase revealed a continuous structure over to the magnetite-hematite boundary shown in Fig. 8d. The latter interface was narrow and followed an irregular contour due to cracking. Stringers of magnetite followed certain cracks which projected into the hematite.

It was concluded from all the studies made on the specimen partially reduced at 500°C that only the three phases, iron, magnetite, and hematite, were present. No wüstite had formed. Discontinuities due to excessive cracking prevented the formation of the well-defined, successive layers observed in specimens partially reduced at 850°C.

The entire sequence of observations was repeated on a cube of the same ore after partial reduction at 650°C. The specimen contained many cracks typical of low temperature reduction and accordingly deviated greatly from an ideal topochemical pattern. However, the number of phases and the phase sequence were exactly the same as in specimens reduced at 850°C.

Summary and Conclusions

An integrated technique was developed for identifying the solid phases in partially reduced iron ore. The procedure followed a coordinated sequence of macro-, micro-, and X-ray examinations.

The reduction of dense iron ore was found to take place at distinct interfaces between well-defined layers of the participating solid phases. The interfaces normally penetrated the ore body in topochemical fashion and remained parallel to the original contour of the specimen.

Four phases, iron, wüstite, magnetite, and hematite, were identified in dense iron ore partially reduced in hydrogen at 850°C. These phases were formed simultaneously as well-defined layers between three reacting interfaces. The same four phases were found on reduction at 650°C. Only three phases, iron, magnetite, and hematite, were found on reduction at 500°C. No wüstite could be identified in any part of the specimen. The phases were orientated in all cases in the order of increasing oxygen content with depth of penetration.

There was a distinct cracking effect which took place during the hydrogen reduction of dense iron ore in the temperature range of 500° to 700°C. This cracking disrupted the topochemical advance of the reduction interfaces and interfered with the formation of well-defined layers.

The reduction interfaces possessed a finite width. This width was a function of temperature and the physical structure and chemical activity of the phases concerned.

The wüstite layer formed during the reduction of dense ore gave a diffuse and broad-lined X-ray pattern. This condition was indicative of a variation in oxygen content across the layer.

References

[1] L. S. Darken and R. W. Gurry: The System: Iron-Oxygen. I. The Wüstite Field and Related Equilibria. *Journal* ACS (1945) **67**, pp. 1398-1412.

[2] L. S. Darken and R. W. Gurry: The System: Iron-Oxygen. II. Equilibria and Thermodynamics of Liquid Oxide and Other Phases. *Journal* ACS (1946) **68**, pp. 798-816.

[3] H. Schenck: *The Physical Chemistry of Steelmaking.* (1945) English Translation. The British Iron and Steel Research Association. London.

[4] P. H. Emmett and J. F. Schultz: Gaseous Thermal Diffusion—the Principle Cause of Discrepancies among Equilibrium Measurements on the Systems: Fe_3O_4-H_2-Fe-H_2O, Fe_3O_4-H_2-FeO-H_2O, and FeO-H_2-Fe-H_2O. *Journal* ACS (1933) **55**, pp. 1376-1389.

[5] E. R. Jette and F. Foote: A Study of the Homogeneity Limits of Wüstite (FeO) by X-Ray Methods. *Trans.* AIME (1933) **105**, pp. 276-289.

[6] E. R. Jette and F. Foote: An X-Ray Study of the Wüstite (FeO) Solid Solutions. *Journal of Chemical Physics* (1933) **1**, pp. 29-36.

[7] *Handbook of Chemistry and Physics.* 33d Edition (1952) Cleveland. Chemical Rubber Publishing Co.

[8] *Metals Handbook* (1948) Cleveland. ASM.

[9] C. Palache, H. Berman, and C. Frondel: *Dana's System of Mineralogy.* 7th Edition (1944) Vol. 1. New York. John Wiley and Sons.

[10] C. S. Barrett: *Structure of Metals.* 2nd Edition (1952) New York. McGraw-Hill Book Co.

[11] I. Langmuir: The Constitution and Fundamental Properties of Solids and Liquids. Part I. Solids. *Journal* ACS (1916) pp. 2263-2267.

[12] C. H. Desch: *The Chemistry of Solids.* (1934) Ithaca, N. Y. Cornell University Press.

[13] B. Kalling and G. Lilljequist: Theoretical Considerations on the Reduction Process, Iron Ore-Iron Sponge. *Teknisk. Tids.* (Bergsv. afd). (1926) **56**, pp. 1-14.

[14] F. Wienert: The Reduction of Iron Ores with Hydrogen and Carbon Monoxide. *Arch. Eisenhuttenwesen* (1933) **7**, pp. 275-279.

[15] W. Baukloh and K. Froeschmann: Reduction Experiments on Iron Ore Cubes in Flowing Hydrogen. *Stahl und Eisen* (1934) **54**, pp. 415-416.

[16] M. H. Kalina and T. L. Joseph: Reducing Iron Ore with Hydrogen. *Iron Age* (1941) **148**, pp. 39-43.

[17] G. I. Chufarov and E. Tatievskaya: The Reaction Zones in the Reduction of Magnetite and Hematite with Hydrogen. *Acta Physicochim. U.R.S.S.* (1935) **3**, pp. 957-974.

[18] K. Hofmann: The Reduction Mechanism of Iron Oxides in Flowing Cases, II. *Ztsch. angew. Chem.* (1925) **38**, pp. 715-721.

[19] F. Olmer: A Method of Study of the Kinetics of Chemical Reaction. *Journal Physical Chemistry* (1943) **47**, pp. 313-317.

[20] F. Olmer: Reduction of Ferric Oxide by Hydrogen. *Journal of Physical Chemistry* (1943) **47**, pp. 317-325.

[21] G. B. Taylor and H. W. Starkweather: Reduction of Metal Oxides by Hydrogen. *Journal* ACS (1930) **52**, p. 2314.

[22] M. Wiberg: The Reduction of Iron Ores with Carbon Monoxide, Hydrogen, and Methane. *Jernkontorets Ann.* (1940) **124**, pp. 179-212.

[23] G. I. Chufarov and B. D. Averbukh: Effect of the Form of Intermediate Phases on the Velocity of Reduction of Iron Oxide by Hydrogen. *Acta Physicochim. U.R.S.S.* (1936) **4**, pp. 617-634.

[24] N. Buinov, A. Komar, M. Zhuravleva, and G. Chufarov: Orientation of the Phases Formed during the Reduction of Magnetite by Hydrogen. *Acta Physicochim. U.R.S.S.* (1939) **11**, pp. 571-584.

Exchange of Iron Between Liquid Metal and Iron Silicate Slag

by G. Derge and C. E. Birchenall

IN studying the kinetics of slag-metal reactions,[1, 2] it has become increasingly apparent that a complete knowledge of all aspects of interface phenomena will be required to clarify these processes adequately. A part of the data required for all oxidizing slags used in the refining of impure iron to steel is the rate of exchange of iron between the slag and metal phases. The simplest equilibrium of this type is that between liquid iron and iron silicate slag when both phases are equilibrated with the silica crucible containing them. In this study, the exchange of iron between the two liquid phases has been measured by using radioactive Fe^{55} as tracer. The observed high exchange rate indicates the ease with which such interfaces may be crossed in refining processes.

The experiments required for this study involved relatively minor and normal modifications of well established techniques. Melting was accomplished by induction heating in heavy walled, fused silica, rotating crucibles.[6] Rotation was used to minimize dilution of the slag by crucible erosion. The melting stock was ingot iron. Slags were prefused in iron crucibles using chemically pure grade oxide reagents. The special conditions applying to the active iron additions will be described for individual experiments. Suitable precautions were observed with regard to protection against radiation hazards.[4]

Identification of Activity

This particular study was initiated several years ago, but held in abeyance because the radioactive iron available at that time contained a foreign activity which concentrated in the slag so as to mask the iron activity and render the results uninterpretable. With the benefit of experiences from other studies, radioiron of suitable purity can now be prepared. As received from the Isotope Div. of A.E.C., the unit appears to contain Fe^{55} + Fe^{59} and a high activity cobalt. The cobalt and iron are separated by repeated ether extractions, and the purified iron stored for sufficient time for the Fe^{59} (44 day half-life) to decay to negligible activity, leaving only Fe^{55} as the active isotope. This was confirmed by the absorption curves for slag and metal samples from heat No. 1. In Fig. 1 the experimentally measured points for the absorption curves of slag and metal are fitted by the calculated slope of 5.8 mg per sq cm in aluminum, which corresponds to the Mn $K\alpha$ doublet emission resulting from the capture of an orbital electron of Fe^{55} by the nucleus. This shows that the radioactive species are the same in both slag and metal and identifies it as Fe^{55}.

Description of Individual Heats

For the first heat, the radioactive iron was contained in the prefused slag. The active Fe^{55} had been precipitated with carrier and was added as Fe_2O_3 during fusion in the iron crucible.

The charge of 500 grams of ingot iron was melted, the protective iron sleeve added, rotation started, and a prefused, inactive slag was added to allow the system to approach equilibrium. After about 5 min at temperature, the wash slag was skimmed and the active slag added. Initial slag and metal samples were taken as soon as the slag was molten. Additional samples were taken at indicated intervals thereafter.

Slag samples were dipped with a small iron spoon and metal samples were sucked into ¼ in. ID silica tubes. The slag and metal samples were pulverized and mounted for radioactive counting. The slag samples were analyzed chemically for FeO.

Temperature was read after the last slag sample by immersion of a Pt-Pt-Rh thermocouple protected by a fused silica sheath. Since no significant variation of rate with temperature was observed

G. DERGE, Member AIME, is associated with Metals Research Laboratory, Carnegie Institute of Technology, Pittsburgh, and C. E. BIRCHENALL, Junior Member AIME, formerly with Metals Research Laboratory, Carnegie Institute of Technology, is now associated with the James Forrestal Research Center, Princeton University, Princeton, N. J.

Discussion on this paper, TP 3576C, may be sent, 2 copies, to AIME by April 1, 1954. Manuscript, March 16, 1953. New York Meeting, February 1954.

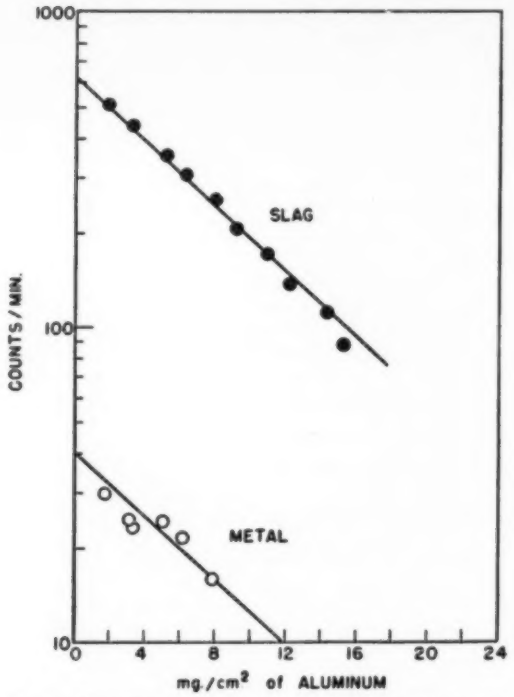


Fig. 1—Absorption curve for radioisotope (Fe^{55}) in slag (upper curve) and metal (lower curve) for heat No. 1.

for three heats ranging from 1530° to 1613°C, the data can be taken as representative of typical steelmaking operations and will be referred to as 1600° hereafter.

The data from this heat indicated the desirability of sampling over a longer time period and using slags of a higher specific activity.

The second heat differed in that the wash slag was not skimmed. This insured equilibrium at the initiation of sampling. The active iron, as oxide mixed with one gram of prefused slag, was contained in a capsule of iron foil and dropped into the already equilibrated "wash" slag. The specific activity was much greater than that of heat No. 1. This procedure was not entirely satisfactory as melting of the capsule was not as rapid or definite as had been anticipated. It was also necessary to terminate sampling prematurely as the third sample caused the slag cover to break.

The third heat was planned to give better data on the final stages of the reaction, since the first two heats showed the initial stages clearly but were interrupted before equilibrium was reached. In this heat, the entire residual slag from second heat was added after the bath had been equilibrated with the slag formed during melting. Samples were taken at longer time intervals to avoid breaking the slag cover before equilibrium was reached. This ran according to plan and was considered the most satisfactory of the group. The plot of activity vs time for both slag and metal from this heat is shown in Fig. 2.

Interpretation of Data

The exact reaction mechanism for the exchange of iron between the two liquid phases of this experiment is not known, and it is only possible to represent the process schematically as

$$Fe_{(iron)} \rightleftharpoons Fe_{(slag)}.$$

In reality the iron may be associated with oxygen or involved in other complexes in both phases, and it is not intended to exclude these possibilities in the above representation. However, in view of the uncertainties indicated, only the simplest possible kinetic treatment is justified. It is not unreasonable to expect first-order behavior, and it will be seen that the data conform well with this assumption.

A standard method[5] of treating first-order kinetic data is the relation

$$k = \frac{2.303}{t} \log \frac{a}{a-x},$$

which may be but in the form

$$t = \frac{2.303}{k} \log a - \frac{2.303}{k} \log (a-x),$$

where t is time, in sec; a, the initial concentration, counts per min; $(a-x)$, the concentration at time, t, counts per min; and k, the first order rate constant. Since $(2.303/k)$ log a is constant, the plot of t vs log $(a-x)$ should be linear and the slope of the line is $-2.303/k$, allowing an evaluation of the rate constant. It is also characteristic of this relation that the numerical value of k is independent of the units used to express concentration. Thus, in the present case, counts per minute may be substituted directly in the above expressions. Fig. 3 shows the plot of

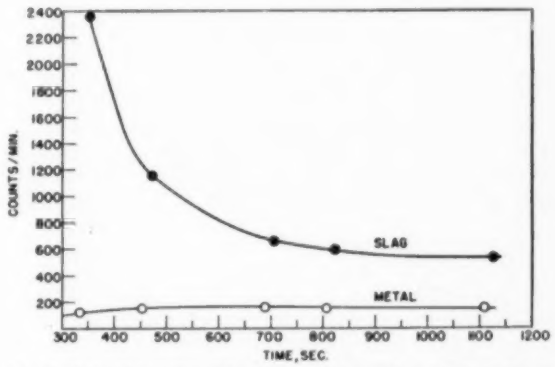


Fig. 2—Rate of transfer of iron between slag and metal, heat No. 3.

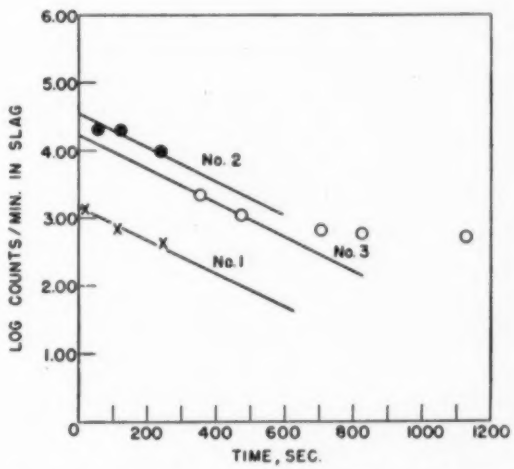


Fig. 3—Kinetic data for rate of transfer of iron between slag and metal.

the logarithm of counts per min vs time for all three heats. It is evident here that in heat No. 3 the reaction had proceeded so far toward equilibrium after 500 sec that the assumptions involved in the rate constant derivation are no longer valid. However, if the data are weighted so as to eliminate the disturbing features of the initial and final stages of the reaction, parallel lines represent all three heats and they all have the same rate constant, $k = 0.006$. In view of the experimental variations described for these heats, this would seem to establish the first-order kinetics of the process.

Another useful characterization of a first-order process is the half-life or time required to reduce the concentration of a reactant by one half. This will be the same at any time during the reaction and is given by

$$t_{1/2} = \frac{2.303}{k} \log 2,$$

where $t_{1/2}$ is the half life of the reaction. In the present case, $t_{1/2}$ equals 115 sec.

These values indicate a relatively rapid exchange of iron across the slag-metal interface, and in order to visualize its significance in metallurgical processes, it is useful to make some simple calculations which permit an estimate of the actual amounts of iron crossing a unit area of the interface. This will be based on the assumption that convection and stirring have been adequate to maintain a uniform composition in the slag and that the slag layer averaged 1 cm thick. Taking a density of 3.57 grams per cu cm[8] for a silica-saturated slag analyzing 57 pct FeO, each cubic centimeter of slag contains 1.58 grams of iron. Thus, under the conditions of this experiment, one half of this amount, 0.79 gram or 0.014 mol, of iron cross the interface from slag to metal every 115 sec, the half-life period. Since the slag and metal are in equilibrium, a like amount must pass in the reverse direction from metal to slag in the same period. On this basis, an interfacial area of 71.5 sq cm is adequate to transfer a gram-mol of iron in each direction every 115 sec. Although many simplifying assumptions have been made in arriving at these figures, it is apparent that the iron-slag interface is a very active site at 1600°C.

Such rates are sufficient to account for observed refining reactions and will help to explain the entire reaction mechanism when other kinetic data are determined.

Conclusions

Using radioactive Fe^{55} as tracer, it has been determined that the equilibrium exchange of iron between silica-saturated iron silicate slag and liquid iron in a silica crucible follows first-order kinetics with a rate constant, k equals 0.006 at 1600°C.

Acknowledgments

This research was done in the Metals Research Laboratory, Carnegie Institute of Technology, with the support of the Office of Naval Research and the American Iron and Steel Institute. The purification of the iron unit and analyses of active slags were carried out by E. E. Duncan. Experimental work was carried out by J. R. Shegog and K. M. Goldman.

References

[1] L. C. Chang and K. M. Goldman: *Trans.* AIME (1948) **176**, pp. 309-329; METALS TECHNOLOGY (June 1948).

[2] G. Derge, W. O. Philbrook, and K. M. Goldman: *Trans.* AIME (1950) **188**, pp. 1111-1119; JOURNAL OF METALS (September 1950).

[3] G. Derge: *Yearbook* AISI (1949) pp. 368-388.

[4] C. E. Birchenall and W. O. Philbrook: *The Iron Age* (Nov. 10, 1949) **164**, pp. 77-82.

[5] S. Glasstone: *Textbook of Physical Chemistry.* (1940) p. 1027. New York. D. Van Nostrand Co.

[6] F. Körber and W. Oelsen: *Mitt. Kaiser-Wilhelm Inst. f. Eisenforschung* (1933) **15**, p. 291.

Technical Note

A Crystallographic Analysis of the Ductile-Brittle Transition In Body-Centered Cubic Single Crystals

by A. J. Opinsky

MANY investigators, in their discussions, have reasoned that the ductile-brittle transition in iron could be explained by the intrusion of cleavage into the normal slip process. The purpose of this note is to apply the laws of critical normal stress for cleavage and critical shear stress for slip to explain the orientation and temperature dependence of the ductile-brittle transition in body-centered cubic metals. It will be found that within a certain temperature range, single crystals tested in tension will cleave or slip, depending on their orientation. Some data recently appearing in the literature will be analyzed from this standpoint.

For a single crystal with $[u\ v\ w]$ parallel to the tensile axis, the resolved shear stress on the slip

A. J. OPINSKY, Junior Member AIME, is associated with the Atomic Energy Div., Sylvania Electric Products Inc., Bayside, N. Y.

TN 202E. Manuscript, Oct. 5, 1953.

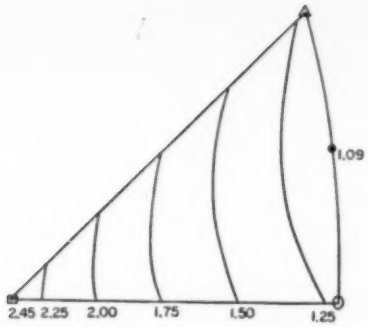


Fig. 1—C/S_{110} contours.

plane in the slip direction can be represented[1,2] by

$$\tau^{111}_{\bar{1}01} = \frac{F}{A} \frac{(u+v+w)(-u+w)}{\sqrt{6}(u^2+v^2+w^2)} \quad [1]$$

$$\tau^{111}_{\bar{2}11} = \frac{F}{A} \frac{(u+v+w)(-2u+v+w)}{\sqrt{18}(u^2+v^2+w^2)} \quad [2]$$

$$\tau^{\bar{1}11}_{\bar{1}12} = \frac{F}{A} \frac{(-u+v+w)(u-v+2w)}{\sqrt{18}(u^2+v^2+w^2)} \quad [3]$$

and the largest normal stress in this unit stereographic triangle by

$$N_{001} = \frac{F}{A} \frac{w^2}{(u^2+v^2+w^2)} . \quad [4]$$

For the beginning of slip $\tau_i = S_i$ (critical shear stress) and for the beginning of cleavage $N = C$ (cleavage stress). Considering first {110} slip, the conventional stress (F/A) at which both slip and cleavage could occur simultaneously leads to the equation

$$\frac{F}{A} = \frac{S_{110}\sqrt{6}(u^2+v^2+w^2)}{(u+v+w)(-u+w)} = \frac{C(u^2+v^2+w^2)}{w^2}$$

or

$$C/S_{110} = \frac{\sqrt{6}\,w^2}{(u+v+w)(-u+w)} . \quad [5]$$

Similar expressions can be developed when {112} slip is considered, except now two systems operate in the chosen unit stereographic triangle, and around [001]

$$C/S_{112} = \frac{\sqrt{18}\,w^2}{(-u+v+w)(u-v+2w)} \quad [6]$$

and near the great circle [011] − [$\bar{1}$11]

$$C/S_{112} = \frac{\sqrt{18}\,w^2}{(u+v+w)(-2u+v+w)} . \quad [7]$$

If various values of C/S_i are chosen, the [$u\ v\ w$] can be calculated, and contours can be drawn, Figs. 1 and 2. From Fig. 1, all crystals will be ductile if $C/S_{110} > 2.45$; all crystals will cleave if $C/S_{110} < 1.09$; if $1.09 \leqq C/S_{110} \leqq 2.45$, the orientation dependence will be as shown. All crystals with tensile axes to the left of the contour will cleave and those with axes to the right of it will slip. A similar argument can be given for Fig. 2. Cleavage with more complicated slip behavior than {110} or {112} can be inferred by using Figs. 1 and 2 as limits. In addition, the temperature dependence can be illustrated by assuming C constant. To make crystals of all orientations brittle, S_{110} would have to rise to more than double its value when cleavage was first noted; this could be accomplished over a rather wide temperature range.

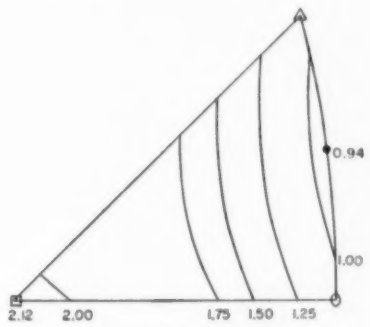


Fig. 2—C/S_{112} contours.

A major objection to the calculation is that twinning is not considered. However, since the criterion for twinning is still disputed, such a calculation would not rest on a firm basis.

The inverse problem, that of determining the C/S_i ratio for a given irrational orientation, can be handled easily by transforming Eqs. 5 or 6 and 7 into spherical polar coordinates. Some recent data[3] showing a temperature dependence of ductile-brittle behavior in high purity ferrites can be thus treated, assuming {110} slip. The pertinent results are that at −108°C, $20{,}200 < C < 28{,}600$ psi; at −118°C, $24{,}800 < C < 30{,}200$ psi; and at −185°C, $C <$ 37,800 psi. The first two limits are in qualitative agreement with a value of 32,000 psi which can be obtained by extrapolating a curve[3] of reduction of area vs cleavage stress to zero. The last value is considerably lower than the extrapolated value of 46,000 psi, but this could be due to the assumption of a low value of S_{110} at −185°C. The actual calculations are given in Table I.

Table I. Calculation of Cleavage Stress from Data of Ref. 3

Specimen No.	Temperature	C/S_{110}	Fracture*	S_{110},† Psi	C, Psi
314	−108	1.26	D	16,000	20,200
342	−108	1.79	B	16,000	28,600
330	−118	1.38	D	18,000	24,800
332	−118	1.68	B	18,000	30,200
349	−118	1.88	B	18,000	33,800
207	−185	1.35	B	28,000	37,800
210	−185	1.37	B	28,000	38,400
224	−185	Not calculated because heavy twinning had occurred			

* Ductile or brittle.
† Read from curve in ref. 3.

References

[1] A. Opinsky and R. Smoluchowski: The Crystallographic Aspect of Slip in Body-Centered Cubic Single Crystals. A Symposium on the Plastic Deformation of Crystalline Solids. Mellon Institute, Pittsburgh. (May 19 and 20, 1950) p. 216.

[2] A. J. Opinsky and R. Smoluchowski: The Crystallographic Aspect of Slip in Body-Centered Cubic Single Crystals. I. Theoretical Considerations. *Journal of Applied Physics* (November 1951) **22**, p. 1380.

[3] R. P. Steijn and R. M. Brick: Flow and Fracture of Single Crystals of High Purity Ferrite. ASM Preprint No. 36 (1953).

After-Effects in Polycrystalline Cadmium

by Charles S. Barrett

The torsional after-effect in polycrystalline cadmium is interrupted by an abnormal twisting when the film is removed by etching. This is accounted for by the pile-up of dislocations beneath anodic or other oxide films during the original twisting, and the relief of the residual stresses from these by elastic and plastic processes during etching.

WHEN an iron or zinc wire coated with oxide is plastically twisted and then released, it untwists according to a law of equal increments in equal intervals of log time, but if the oxide is suddenly removed by etching this normal after-effect is interrupted by a transient, and thereafter the untwisting is slower.[1] Etching may even reverse the strain temporarily.

Related effects caused by hydrated oxide films on cadmium in creep tests have been observed by Phillips and Thompson:[2] definite transient strains caused by the removal of the film from single crystals of cadmium were observed; however, negligible effects were obtained with *polycrystalline* wires. Pronounced effects of both transient and steady nature were observed by Phillips and Thompson when anodic films 10^{-4} cm thick were etched off, and weak effects, transient only, occurred with hydrated oxide films 3×10^{-6} cm thick such as were formed by standing in water for 10 min. It was estimated that 10^{-7} cm films, formed in water in 1 or 2 min, could be detected in the apparatus of Phillips and Thompson.

Since abnormal after-effects were observed by the torsion method equally well with polycrystalline and monocrystalline iron and zinc wires,[1] it was anticipated that the torsion method would also disclose them in polycrystalline cadmium, in spite of the fact that analogous effects had not been observed in tensile creep tests on polycrystalline zinc by Pickus and Parker[3] or on polycrystalline cadmium in tensile studies by Andrade and Randall.[4]

Because of its high sensitivity, particularly its sensitivity to surface conditions, the torsion method was thought to merit further study as a method of investigating thin films of various types and the action of various reagents on these films.

Materials and Methods

Cadmium wires were cold-drawn to a diameter of 0.039 in. from a stock that was determined spectroscopically to contain 0.05 pct Bi, 0.005 pct Cu, 0.008 pct Pb, and 0.007 pct Si. The wires were cut to about 1⅞ in. lengths and were annealed 1 hr in air at 290°C, after which the grain size was such that there were 5 to 7 grains across a diameter. The wires were then mounted as indicated in the insert in Fig. 1, one end being fastened with laboratory wax into a small diameter brass tube and the other end being waxed to a thin glass fiber which supported, on its upper end, a small galvanometer mirror. The wires were waxed with care to avoid straining or annealing, for it was found that the after-effect rate was sensitive to prior cold work in a wire. The assembly was then clamped above a beaker into which the reagent could be poured. The lower end of the wire was held in the hand while the wire was twisted 180°; it was then released immediately. Since precision timing of these manipulations was not attempted, the different wires cannot be compared as to exact rates of untwisting. The length subjected to plastic strain was 1⅝ in.

The surface coatings studied were those produced by the annealing in air, by anodic treatment of

C. S. BARRETT, Member AIME, is associated with the Institute for the Study of Metals, University of Chicago, Chicago.

Discussion on this paper, TP 3675E, may be sent, 2 copies, to AIME by Feb. 1, 1954. Manuscript April 24, 1953; revision, July 27, 1953.

etched wires in a potassium hydroxide bath, and by immersion in distilled water.

Results

The principal results are summarized in Fig. 1, where the strain during the untwisting period is plotted vs log time, a plot that has been found[1] to give straight lines for the normal after-effect in most cases. In Fig. 1 the specimens were immersed in water, beginning at the times marked *W* and immersed in the etching solution at the times marked *E*. The rate of untwisting may be seen from the scale of degrees given, which has been displaced an arbitrary amount vertically for each curve, i.e., the zero position on this scale is without significance.

In curve *A*, which applies to a wire that had been oxidized at 290°C in air for 1 hr, the untwisting that occurred at 26°C after a twist of 180° in a length of 1⅝ in. was altered at point *E* by immersion in 0.25 pct H_2SO_4 at the same temperature. An abnormal after-effect resulted, the untwisting changing to a twisting. At time 19 min the etchant was replaced by water (distilled water was used throughout these tests) and an after-effect that was in the normal direction, but slower, was resumed. When this experiment was repeated on another wire with water at 2.5°C and with an etchant of 2 pct H_2SO_4 at 2.5°C, the initial slope was the same but the transient in the curve after applying the acid showed a downward trend—with a strain rate less than the original rate of untwisting—rather than an upward trend.

Curve *B* also applies to a specimen that had been annealed in air at 290°C for 1 hr and that was given two successive etches during untwisting and was maintained in water before and after the etchings. The first etching was for ½ min in 0.25 pct H_2SO_4 beginning 9 min after twisting (point *E*); this changed the untwisting rate markedly. The second etching was done similarly, 19 min after twisting (point *E'*); there was almost no change in the untwisting rate as a result of this. The same specimen, 35 min after twisting, was twisted again 180° and the subsequent after-effect is plotted as curve *C*; when 0.25 pct H_2SO_4 replaced the water at *E* on this curve, there was no change in slope. Thus twisting the freshly etched wire does not lead to transients and rate change upon etching, and once an untwisting wire has been cleaned of its oxide by etching, subsequent etching produces no further rate changes.

Curves *D* and *F* show the large transients that occur upon removal of anodic films. For curve *D*, 2 pct H_2SO_4 was applied at the time indicated by *E*, and for curve *F* the etchant was 0.1 pct H_2SO_4; the experiments were run at 27°C. It is seen that the stronger acid caused a shorter transient, as would be expected if it more quickly destroyed the anodic coating. It should be remarked regarding the shortness of the transient in curve *D* that visual evidence of the anodic coating disappeared in a few seconds with this etchant. No conclusions should be drawn from the greater magnitude of the transient in *D* compared with that in *F*, since the initial slopes of the curves also differed—the initial structure and the strain history of the wires was not controlled with sufficient accuracy for these slopes to be closely matched.

If the sensitivity of the method is judged by the rate changes caused by the removal of hydrated oxide films formed in water, the experiments covered by curves *B* and *C* and another, not reproduced, suggest that films must form for longer times than 10 min in distilled water if they are to yield clearly discernible effects. The work of Phillips and Thompson[2] shows that such a film is about 3×10^{-8} cm thick and by their method this could be detected on single crystals. The present sensitivity, at least for polycrystals, is apparently less, but nevertheless it is very high, for an obvious change of slope, from 0.33 to 0.29 degrees per decade of log time, was observed when 2 pct H_2SO_4 was applied to an etched wire on which an oxide had been forming during 40 min in air at 25°C.

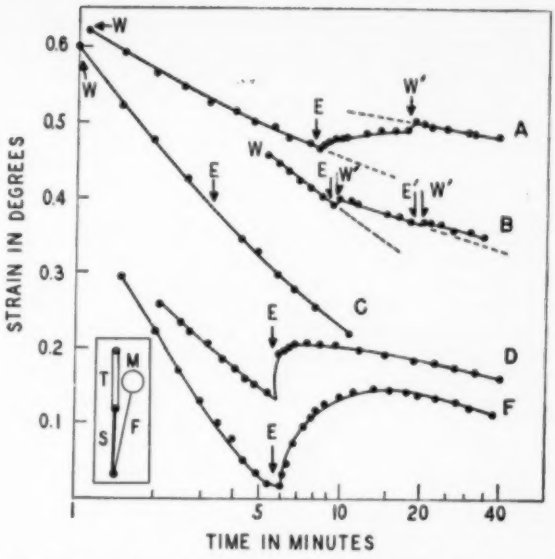


Fig. 1—Insert shows method of mounting specimens for the torsion experiments. Specimen *S* is waxed at one end to a glass fiber *F* supporting galvanometer mirror *M* and at the other end is waxed to tube *T*. Curves are for untwisting in water at *W* and *W'*, and in etchant at *E* and *E'*.

A—Oxidized 1 hr at 290°C, 0.25 pct H_2SO_4 applied at *E*.
B—Oxidized 1 hr at 290°C, 0.25 pct H_2SO_4 applied at *E* and *E'*.
C—Previously etched, 0.25 pct H_2SO_4 applied at *E*.
D—Anodic film. 2 pct H_2SO_4 applied at *E*.
F—Anodic film. 0.1 pct H_2SO_4 applied at *E*.

The strong influence of the oxide film is not removed by moderate plastic deformation of the wire. A specimen containing an oxide formed in air at 290°C was bent around a 5/16 in. mandrel, straightened, bent oppositely around the mandrel, straightened, and then twisted in the usual way. The subsequent untwisting was at an unusually high rate, 0.71 degrees per cycle of log time. Nevertheless, the effect of etching with 0.25 pct H_2SO_4 at time 6 min was definite, changing the rate to 0.63.

When a wire that had been oxidized at 290°C was allowed to untwist in air and then was suddenly immersed in water, it was found that no change of slope occurred, although the galvanometer mirror was subject to an abrupt displacement due to buoyancy effects. It was also found that results with wires that were twisted while immersed in water did not differ essentially from results obtained after twisting in air. These experiments did not reveal any important altering of properties of the surface film by water—at least in a matter of minutes.

Discussion

Every explanation that appears capable of explaining the abnormal after-effect involves the same

fundamental mechanism, namely, release by one means or another of residual stresses that have been built up when a surface layer has acted as a barrier to the escape of dislocation loops generated within the metal, and has resisted plastic flow more than the underlying layers. The residual stresses result directly from the piling up of dislocations beneath the surface, as suggested by Cottrell before the effect was discovered. Three methods of relief of these stresses are discussed below.

1—The stresses may be released by the escape of the piled-up dislocations through the surface. Since their motion in escaping is in the same direction as it was during the original twisting, the transient strains accompanying their escape are in the direction of twisting rather than untwisting.[1] Dislocations leaving the metal subsequently counterbalance in part those lying deeper within the metal that are returning toward their source in the normal after-effect, so that the rate of untwisting after the transient is completed is always less. With weaker acids, the surface film is destroyed more gradually and the escaping is initiated more slowly (curve *F* vs curve *D*). If a wire lacks a surface film at the time of twisting, no pile-up occurs. (Curve C is an example.)

2—The stresses may also be released by a twist that is elastic rather than plastic, as in a stress-analysis experiment, when the surface film is etched away. The transient strain thus introduced will be in the observed direction if at the time of twisting the surface film had a higher yield strength than the underlying metal.

While such elastic strain may well play a part in the stress readjustment, there is good reason to believe it cannot be the whole effect. Dislocation theory indicates that the spearhead of the dislocation pile must approach to within a distance that is only of the order of 10^{-7} cm from the barrier created by such a film, and since the following dislocations force the leading ones toward the surface, it is to be expected that some will move the remaining distance to the surface when the barrier is removed, being repelled by the local stress fields of the pile—just as the innermost dislocations of the pile are being forced back toward their source by the stress field of the pile, producing the normal after-effect.

3—A third possible mechanism for stress relief[1, 5, 6] is the springing into operation of dislocation generators, located at the metal surface, that have been kept inactive by the presence of the oxide. If the direction of the shear stresses on the surface is examined, it will be found that there is one direction for stresses within a set of piled-up dislocation loops and the opposite direction for those outside of the pile (in other words, one direction in the areas along the side of a slip line, the opposite direction in the areas beyond the ends of a slip line). On this basis it was suggested[1] that if there were dislocation generators at the surface suddenly becoming active, they would have opposing signs in the two areas and could not therefore explain the abnormal after-effect. This implies the doubtful assumption, however, that the local shear stresses in the surface are in balance in such a way that their effects on surface sources would cancel. It is reasonable to expect, on the contrary, that the net rotational moment from residual stresses in the surface is not zero, and is balanced by that in underlying layers. Therefore suddenly activated surface generators could add to mechanisms 1 and 2 above in relieving the residual stresses. Surface generators may also be active in tensile stressing.

Coffin and Weiman propose that a thermal transient occurs when etching removes a surface film and that this accounts for the increased creep rate in tensile creep tests.[8] While this may apply when the action of an etchant on a surface film is vigorous, it can be progressively reduced by diluting the etchant. Since the effects discussed in this paper and the preceding one[1] are found with very dilute acids and are not removed by further dilution, it is concluded that this theory does not apply.

Coffin and Weiman[8] propose, also, that a thermal transient would occur and increase the creep rate even when no oxide film is present, and, finding such an effect with a "clean" surface, they conclude that a thermal transient does occur. In our previous after-effect tests, however, transients were not observed with clean metal,[1] and this is confirmed in the present tests. The Coffin-Weiman strain transients may have been caused by invisible oxide layers formed inadvertently at room temperature.

It is concluded that experiments of this type provide a sensitive and unusually simple method of obtaining information on surface conditions that influence mechanical properties of metals, particularly creep resistance at low loads.[8] It is felt that a more detailed study of the method is merited, and in current investigations the method is being applied in more quantitative fashion to a study of various oxide films on high purity aluminum.

Summary

1—Torsion tests on polycrystalline cadmium wires disclosed abnormal after-effects when anodic or other oxide films on the wires were etched, as has been observed with iron and zinc wires.

2—The sensitivity of the test was sufficient to detect the films formed in air at room temperature in fractions of an hour.

3—The oxide films retained their influence after the wire had been subjected to moderate plastic deformation.

4—Prior cold work increased the rate of untwisting in the normal after-effect; the transient abnormal effect was slower when the etchant was more dilute.

5—The results are accounted for by the theory that the oxide-metal interface is a barrier to dislocations and that the residual stresses from dislocations piled up beneath the interface are relieved by elastic and plastic processes during etching. Control tests indicated that thermal transients were not involved.

Acknowledgment

This work was supported in part by Contract N6ori-02004, U. S. Office of Naval Research.

References

[1] C. S. Barrett: *Acta Metallurgica* (1953) **1**, p. 2.

[5] D. J. Phillips and N. Thompson: *Proc.* Physical Soc., London (1950) **B63**, p. 839.

[6] M. R. Pickus and E. R. Parker: *Trans.* AIME (1951) **191**, p. 792; JOURNAL OF METALS (September 1951).

[4] E. N. da C. Andrade and R. F. Y. Randall: *Nature* (1948) **162**, p. 890; *Proc.* Physical Soc., London (1952) **B65**, p. 445.

[5] John J. Gilman and T. A. Read: *Trans.* AIME (1952) **194**, p. 875; JOURNAL OF METALS (August 1952).

[8] F. D. Coffin and A. L. Weiman: *Journal of Applied Physics* (1953) **24**, p. 282.

[7] T. A. Read: Private communication.

[8] J. E. Fisher: Discussion on ref. 3. *Trans.* AIME (1952) **194**, p. 531; JOURNAL OF METALS (May 1952).

Torsional After-Effect Measurement and Applications To Aluminum

by C. S. Barrett, P. M. Aziz, and I. Markson

The abnormal after-effect in twisted wires that occurs when untwisting is interrupted by etching can be brought under control and used to study the mechanical properties of thin surface films and how they are effected by reagents and heat treatment. Results are given of studies of oxide films on high purity aluminum.

IF a wire is subjected to plastic deformation by torsion and then released, it untwists in the normal after-effect, but under certain circumstances the untwisting is abruptly lessened or reversed by the application of an etchant to the wire.[1, 2] This abnormal after-effect may occur, for example, if there is a coherent oxide film on the surface of the wire which is removed by the etchant.

Following a suggestion of A. H. Cottrell that predicted this effect, it is attributed to dislocations that had piled up beneath the oxide layer and represents the rapid release of residual stresses caused by these dislocations. When the layer is removed, the stress relief may be by escape of piled-up dislocations from the metal, or by an activation of latent sources of dislocations located at the surface, together with rebalancing of elastic stresses to compensate for the loss of stressed material, as in a residual stress analysis determination, these mechanisms acting singly or in combination.[3] The slower the attack of the reagent, the more gradual is the stress relief and the smaller the change in strain rate when the reagent is applied.

A study has been made of the factors that influence the magnitude of the normal and abnormal after-effects with the object of developing techniques suitable for a quantitative investigation of the influence of various surface films on dislocations in wires, and of the rate and extent of the attack on the films by different reagents. It was found that reasonable sensitivity and reproducibility could be achieved if a suitable choice of variables was made and if these variables were held constant through a series of experiments. The method was then applied to a study of oxide films produced and treated in different ways on the surface of high purity aluminum wires, and to a study of the damage to these films caused by various reagents.

C. S. BARRETT, Member AIME, is associated with the Institute for the Study of Metals, University of Chicago, Chicago, and P. M. AZIZ, with Aluminium Laboratories Ltd., Kingston, Ont., Canada, and I. MARKSON, Glasgow, Scotland, were at the University of Chicago during these experiments, the latter as Mutual Security Agency Fellow.

Discussion on this paper, TP 3667E, may be sent, 2 copies, to AIME by April 1, 1954. Manuscript, Aug. 7, 1953. New York Meeting, February 1954.

Experimental Procedure

The material used throughout this work was prepared from 99.9968 pct Al. This high purity aluminum was melted, cast into ½ in. diameter ingots, and then swaged and drawn without intermediate annealing to 0.040 in. diameter wire. A sketch of the apparatus employed for twisting is shown in Fig. 1. The test wires were mounted into the apparatus by cementing one end of the wire to the beaker and the other to the tube with laboratory wax of high melting point. The length of the wire between the waxed joints was 4.2 ± 0.2 cm. Extreme care was taken during mounting to avoid cold-working the wire.

The wire was twisted through 335° in 2 to 4 sec by rotating the pinion on the gear box until the vertical post on the rotating table, which was initially touching the horizontal stop, was arrested by the stop. All the tests were conducted with apparatus and reagents at the same temperature (about 25°C). In all tests, except those where the duration of the initial torque was investigated, the torque was applied for a period of 2 min. At the end of this time the table was rotated back a few degrees away from contact with the stop and the wire allowed to untwist. The after-effects were measured by reflecting a beam of light from the mirror shown on the apparatus. After the wire had untwisted for 6 min, a reagent was carefully poured into the beaker and thereby applied to the surface of the wire. In some tests the liquid in the beaker was removed after a few minutes and replaced by an-

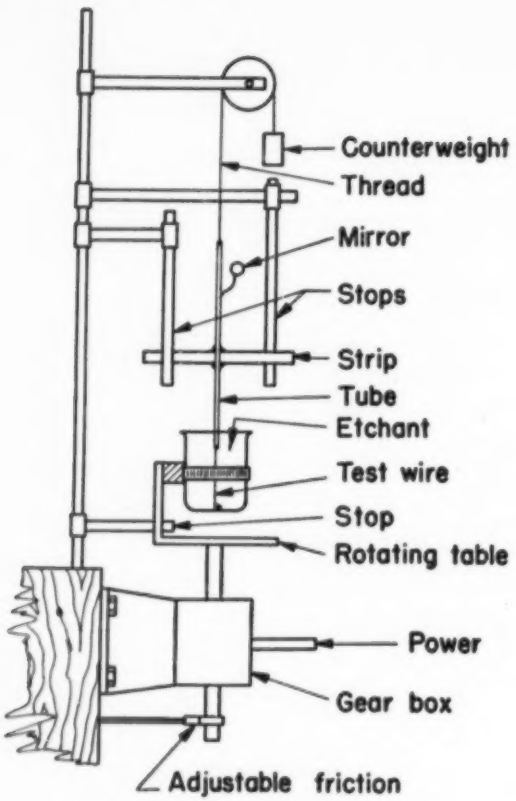


Fig. 1—Sketch of experimental apparatus.

other liquid. In these cases of replacement the second liquid would contain traces of the first reagent, to the extent of about 1 pct.

The data obtained were plotted as curves of strain vs log time and, as anticipated from previous work, linear curves were obtained for the normal after-effects, and frequently, also, for the abnormal ones. The curves were extrapolated and their slopes denoted by the strain in degrees between 10° and 10^{n+1} min, a "cycle" of the log time plot. This was found to be a convenient method of comparing after-effects in different tests.

Very erratic results were obtained in the preliminary tests that were carried out on wires covered with the original oxide film that formed during casting and swaging. This film, crushed into the metal and cracked during the process of drawing, could not be expected to have a high degree of uniformity. It was therefore removed, either after drawing or, if a wire was annealed, after annealing, and replaced by a film formed in air, water, or a furnace, or by an anodic film. Apart from one early test (curve *D*, Fig. 4) in which the original film was removed by etching for 2 min in 85 pct H_3PO_4 at 70°C, the original films in all other tests were removed by chemically polishing, using the "R-5 Bright Dip" process (under a license from the Aluminum Co. of America and according to the technique suggested by F. Keller of that company). The wire when rinsed in water or acetone and dried in an air blast had a brightly polished surface covered with an extremely thin invisible oxide film.

The possibility must be considered that the abnormal after-effect may be due to the direct attack of the reagent on the aluminum itself instead of the oxide. In the present work this is believed to be very unlikely. During the course of each run the surface of the wire was examined while immersed in the reagent, and visible gas evolution, which would indicate attack of the metal, was never observed. Furthermore, when wires carrying anodic films were twisted, very fine cracks appeared in the film. Microscopic examinations of these cracks after immersion in the reagent showed no widening or undercutting of the crack, indicating that attack of the metal had not taken place.

Results and Discussion

To obtain quantitative and reproducible results in tests of this nature it is obviously necessary to maintain control of geometrical variables such as the diameter and length of the wires and the angle through which the wires are initially twisted. Control of certain other somewhat less obvious variables is also necessary. These are the amount of cold work received by the wire previous to twisting, the amount of recovery or recrystallization that has taken place subsequent to the cold working, the grain size of the wire, the duration of the initial application of torque, and the thickness and nature of the oxide film covering the wire. These effects were investigated and the results are presented in Figs. 2 to 4, inclusive; a detailed discussion of these and subsequent figures appears in the sections to follow.

One of the variables that alters the abnormal after-effect rate is the time that elapses before the reagent is applied. In all tests reported here this was held constant at 6 min.

It has been suggested that when the medium at the surface of the wire is changed, the change of surface energy at the interface between metal and solution might allow slip to occur more easily and therefore contribute to the abnormal after-effect. Several tests were therefore carried out to determine the effects of changing surface tension, Fig. 5.

In addition to studying the factors affecting the magnitude and reproducibility of the abnormal after-effect, a series of experiments dealing with the attack of the oxide film by etchants was carried out. This was done by subjecting both anodic and high temperature oxide films to a series of organic and mineral acids and to different pretreatments such as annealing, treating with distilled water (a process known as sealing) at various temperatures, and pre-etching for different times, Figs. 6 to 11.

The presentation and discussion of the results are given in two parts, corresponding to 1—the study of the variables influencing both the normal and abnormal effect, and 2—the use of the abnormal after-effect in studying various films on aluminum and their attack by reagents.

Variables Affecting the Normal and Abnormal After-Effects

Fig. 2 shows the effect of the duration of the applied strain (time of holding) on the initial rate of untwisting in the normal after-effect. The wires used for these tests were annealed for 1½ hr at 285°C and chemically polished. All of the wires were twisted in the standard fashion and, after being held for various times at this strain, were released and the rate of untwisting measured. The time of holding was measured as the time from the commencement of twisting until the load was final-

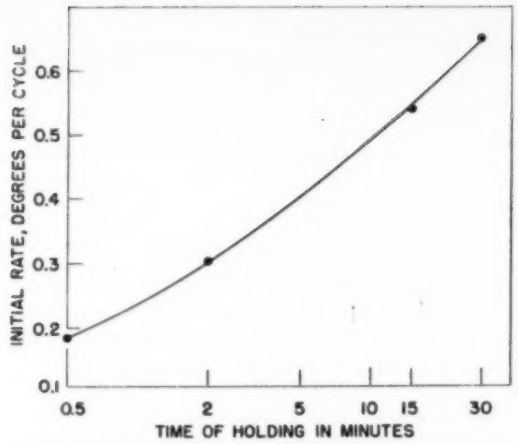


Fig. 2—Influence of time of holding at constant strain on the initial strain rate in air, in degrees per cycle of log time in minutes.

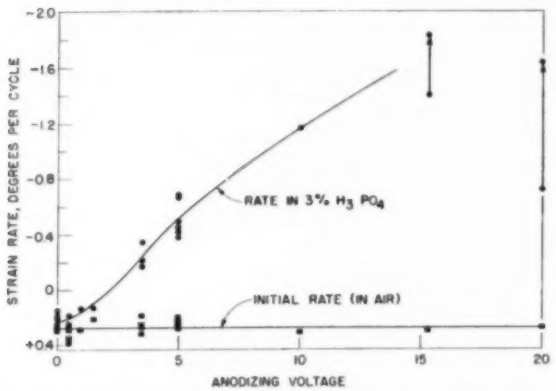


Fig. 3—Influence of anodic oxide film thickness measured in terms of the anodizing voltage on the initial strain rate in air and in 3 pct H_3PO_4.

ly released. The initial rate of untwisting is seen to depend quite strongly on the time of holding and this variable was therefore controlled, at an arbitrary value of 2 min, in the remainder of the tests on aluminum discussed below.

The influence of film thickness was studied by forming oxide films anodically in a 3 pct chromic acid bath at 70°C on wires annealed 1½ hr at 285°C. As it is known that increasing the anodizing voltage increases the film thickness, a range of anodizing voltages was used giving a range of thicknesses. The measured strain rates in air and 3 pct phosphoric acid as a function of anodizing voltage are shown in Fig. 3. For the thinner coatings, produced at voltages less than 15 v, the change in strain rate when 3 pct phosphoric acid is applied increases with the anodizing voltage and hence with the film thickness. This is interpreted as indicating that the thicker coatings provide more effective barriers for stopping dislocations. For coatings thicker than these, the initial effect of etching was less pronounced, and the strain rate increased after a few minutes in acid (this is indicated by the vertical arrows in Fig. 3). Assuming a uniform rate of attack of the acid, this would indicate lower stresses in the outer layers of the oxide than in the layers near the interface. An unexpected result in Fig. 3 is that the strain rate in the normal after-effect, i.e., before etching, is virtually independent of the anodizing voltage that had been used in preparing the wire.

Although the variation of strain rates in 3 pct phosphoric acid for a given thickness of film on different wires is considerable (−0.38 to −0.69 degrees per cycle for a 5 v film), the curve might be used as a rough indication of the thickness of a film (in terms of anodizing voltage) produced in a chromic acid bath, or as a test of the effect of various treatments on a standard type of film. For further tests on the effect of different treatments on anodic films, 5 v chromic acid films were employed.

The effect of cold work and annealing on the initial rate is shown in Fig. 4. The rapid untwisting of cold-drawn wire illustrated by curve *A* is attributed to the many residual dislocations and local stresses within the cold-worked metal that act as barriers to the growth of the dislocation rings formed during twisting. The abnormally large number of these barriers compared with the number in annealed wires results in shorter average distances between barriers and dislocation generators, therefore in more tightly packed arrays of dislocations piled up against the barriers, and in more rapid return of the dislocations toward their source during the untwisting period. Annealing the wire before twisting reduced the barriers and lowered the untwisting rate, as seen in curve *B* for wire recovered and partially recrystallized by a 1 hr anneal at 250°C. Additional annealing still further reduced the rate, curves *C* and *D*.

Comparison of curves *C* and *D* shows the effect of grain size in fully recrystallized wire on the initial rate of untwisting. Here again the rate is doubtless governed by the number of barriers that block or impede the motion of dislocations, the obvious bar-

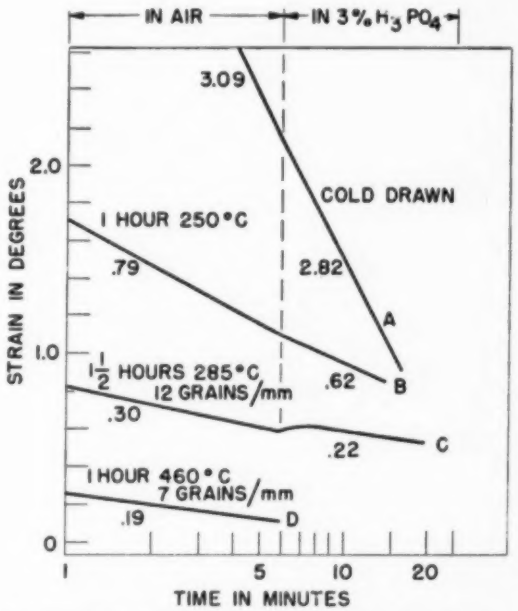


Fig. 4—Effect on the initial strain rate in air of cold working and of annealing chemically polished wires with air-formed oxide. Heat treatment, grain sizes, and strain rates are given. The zero positions on all scales of strain here and in the figures that follow are arbitrary.

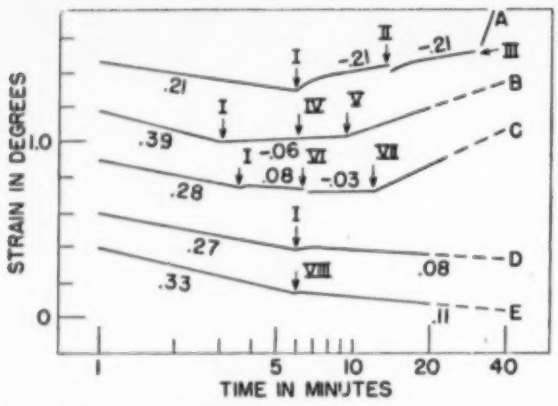


Fig. 5—Effect of surface tension on strain rates. Surface conditions employed: *A,B*—Annealed 2 hr at 460°C, anodized in 3 pct chromic acid at 50 v. *C*—Annealed 2 hr at 460°C, anodized in 3 pct chromic acid at 25 v. *D,E*—Annealed 1½ hr at 285°C, anodized in 3 pct chromic acid at 5 v. Numerical values of strain rates given in figure. At I, wire immersed in distilled water; at II, ½ volume of technical methyl alcohol added; and at III, ½ volume of 3 pct H_3PO_4 added. At IV and V, respectively, 1 ml of aerosol and 10 ml 3 pct H_3PO_4 added. At VI, wire immersed in 50 pct ethyl alcohol, and at VII, ¼ volume of 3 pct H_2SO_4 added. At VIII, wire immersed in a 50 pct solution of ethyl alcohol in distilled water.

riers in this case being the grain boundaries, though less obvious ones, perhaps subboundaries, may also play a part.

With larger grain sizes a larger statistical fluctuation in the number of grain boundaries and less reproducibility in initial rate was anticipated. The greater part of further work was therefore carried out on wires annealed 1½ hr at 285°C, the minimum annealing treatment that was judged adequate to insure complete recrystallization, as estimated from Laue photographs of the annealed wires. Reproducibility might be increased, also, by increasing the length and diameter of the wires, although this was not tried. Ten to twenty scale readings were taken in determining each untwisting curve; the individual points are not reproduced but are represented to width-of-line accuracy by the lines shown in the figures. All deficiency in reproducibility lay in manipulations and in the specimen itself rather than in taking scale readings.

Several tests were carried out in order to determine whether surface tension changes contribute appreciably to the abnormal after-effect. The results are presented in Fig. 5. Curves *A*, *B*, and *C* show that practically no change in the after-effect rate occurs when the surface tension of distilled water surrounding a wire is altered by the addition of methyl alcohol, aerosol, or ethyl alcohol. When a reagent such as phosphoric acid is added, however, which is known to attack the oxide layer, there is a sudden change in the strain rate.

Since it could be argued that the reagents added for the purpose of altering surface tension might not have sufficient time to diffuse through water into fissures or pores in the oxide and alter surface energy of the underlying metal, a further test was carried out in which the different liquids were mixed together before application to the surface of the wire. This test is recorded in curve *E*. Comparison of curve *E* with curve *D* shows again that the change in surface tension due to the ethyl alcohol has had a negligible influence on the abnormal after-effect.

Study of Various Films on Aluminum and Their Attack by Reagents

The effect of different reagents on the surface oxide film on aluminum is not fully understood and while the terms "solvent action" and "dissolving" are used they are not to be construed in the sense of a complete solution of the oxide in the reagent. The reaction of aluminum with water is attended with a very large free energy decrease and it is only the presence of a surface oxide film that restrains this reaction from taking place with almost explosive violence. As has already been stated, no gas evolution was observed to take place from the surface of the wire during the course of these experiments and hence it must be assumed that some sort of surface film is retained on the wire even when immersed in the reagent. It is felt that while some direct superficial solution of the film takes place, the preponderent effect of the reagent is to penetrate and peptize the film, thus reducing its mechanical strength. These two effects will act simultaneously and it is their total effect that is observed, therefore the terms mentioned will be used to denote the general effect of the reagent on the film.

The alteration of strain rate on changing from air to a reagent was measured, for a series of reagents, on a set of wires that had been annealed 1½ hr at 285°C, chemically polished, and anodized (3 pct chromic acid, 5 v). The results are given in Fig. 6.

The solvent action of a 2 pct boric acid, 0.25 pct ammonium hydroxide solution on anodic films is known to be very small and this fact is confirmed by the small change in strain rate when that reagent is used, as the results given in curve *A* show. The changes in strain rate produced by 2 pct sulphuric acid, distilled water, 3 pct acetic acid, 3 pct oxalic acid, and 3 pct formic acid as shown in curves *B* to *F*, inclusive, suggest that all these reagents have an approximately equal effect on the film. In practice, commercial aluminum alloys are only very slightly corroded by these reagents although to somewhat

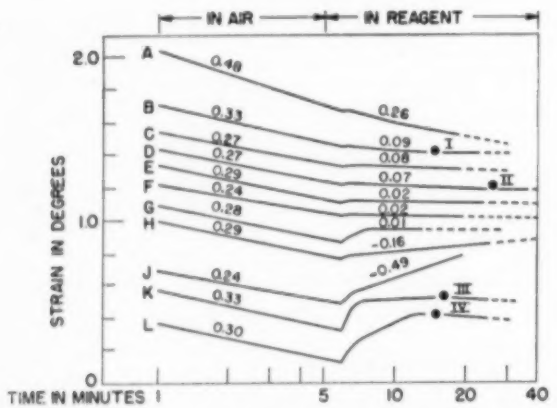


Fig. 6—Effect of a series of reagents on a 5 v chromic acid anodic film. At I and II changed to distilled water, rate became 0.00. At III and IV changed to 2 pct H_3BO_3 plus 0.25 pct HN_4OH solution and rate became 0.08 and 0.14, respectively. The strain rates in air and in the reagent are given beside the curves. Curve and reagent: *A*—2 pct H_3BO_3 plus 0.25 pct NH_4OH. *B*—2 pct H_2SO_4. *C*—Distilled water. *D*—3 pct acetic acid. *E*—3 pct oxalic acid. *F*—3 pct formic acid. *G*—25 pct HCl. *H*—3 pct H_3PO_4 plus 2 pct chromic acid. *J*—3 pct H_3PO_4. *K*—3 pct NaOH. *L*—3 pct NH_4OH.

differing degrees, and the fact that the present technique shows very little difference between the effects of any of these reagents may be attributed to the high purity of the metal used. The oxide film on this material will be much more continuous and stable since it will not contain the oxidation products of the various alloying elements and impurities of commercial alloys.

The effect of 25 pct hydrochloric acid is shown by curve *G* to be of the same order of magnitude as that of the reagents just discussed, so that here again the oxide film is rather resistant to the reagent, which is to be expected from the fact[5] that the oxide film formed by thermal treatment on high purity (99.95 pct) aluminum is relatively insoluble in 25 pct hydrochloric acid. The effect of adding chromic acid to phosphoric acid is shown by curve *H* when compared with curve *J* for phosphoric alone; the inhibitive action of the chromic acid slows down the rate of attack.

The rapid attack of 3 pct sodium hydroxide is indicated by curve *K* and by results to be subsequently presented in Fig. 9 which show that pre-etching the film for 9 min in this reagent is sufficient to dissolve it completely. The initial rapid change in strain rate in curve *K* indicates that most of the attack occurs in the first 2 min. Similar results, presented in curve *L*, were obtained with 3 pct ammonium hydroxide, although this reagent attacked the film over an 8 to 10 min period.

The magnitude of the transient strain in the reverse direction accompanying a sudden removal of oxide as in curve *K* should be an index of the intensity of stresses in the oxide layer, therefore an index of the ability of the layer to impede the emergence of dislocations (provided the attack is not so violent as to introduce other effects such as transient heating of the wire.)

Fig. 7 gives the results of a series of measurements carried out on oxide films formed under various conditions on wire specimens previously cleaned in the standard fashion. The curves indicate the effectiveness of these films in causing dislocations to pile up and the rate with which the application of 3 pct phosphoric acid relieved the stresses.

Curves *A* to *E* give the results obtained on a series of sulphuric acid and boric acid anodic films. These two anodizing baths are known to give anodic films with different types of structure. The sulphuric acid film is thick and porous, whereas the boric acid film is thin and compact. The extremely high strain rate obtained on curve *A* on immersion in 3 pct phosphoric acid indicates that the sulphuric acid film is a good barrier for dislocations but is easily and rapidly weakened by immersion in the reagent. This behavior is not changed by sealing in either 5 pct potassium chromate solution having a pH of 3.8, or in distilled water adjusted to a pH of 3.5 with nitric acid. This is surprising since sealing swells and consolidates the film and confers added corrosion resistance to the anodized metal, the presence of chromate in the sealant generally conferring especially good corrosion resistance on the metal. However, as curve *D* shows, sealing in distilled water gives a very much slower rate of attack by the reagent. Thus it appears that the efficiency of a sealant depends on its pH and is very poor at pH values around 3.8.

Anodic films prepared in boric acid electrolytes are known to be of the compact, nonporous type. It would be expected, therefore, that these would exhibit a high resistance to 3 pct phosphoric acid; this is in accord with the small change in rate when the etchant is applied in curve *E*. Another contributing cause of the small magnitude of the effect is doubtless the thinness of the film, for presumably it is less able to block the escape of dislocations during the initial twisting. (When it is desired to discriminate between the two causes, a series of pre-etching experiments can be conducted as was done in the experiments of Fig. 9, discussed later.)

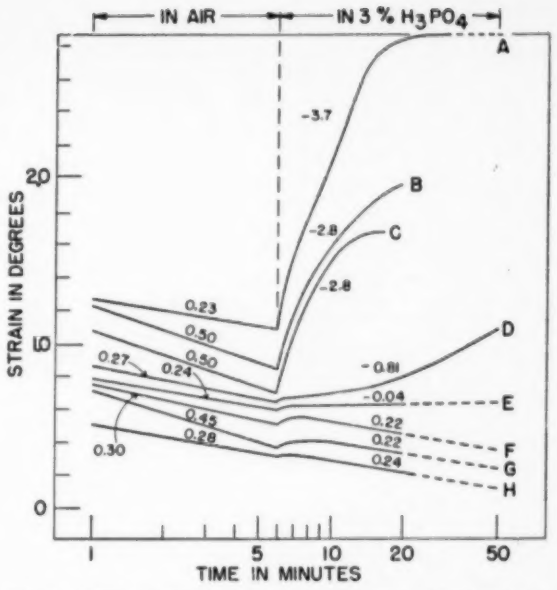


Fig. 7—Effect of phosphoric acid on oxide films formed under a variety of conditions. The strain rates in air and the reagent are given by the appropriate curve. Preparation of oxide films: *A*—Anodized at 5 v for 5 min in 18 pct H_2SO_4 at 20°C. *B*—As in *A*, then 30 min at 100°C in 5 pct $K_2Cr_2O_7$ solution (pH, 3.8). *C*—As in *A*, then 30 min at 100°C in 0.001 normal HNO_3 (pH, 3.5). *D*—As in *A*, then 30 min at 100°C in distilled water. *E*—Anodized for 5 min at 12 v in 2 pct H_3BO_3 plus 0.9 pct NH_4OH solution at 20°C. *F*—Oxidized 1 hr in the atmosphere. *G*—Oxidized 1½ hr at 285°C. *H*—Held in distilled water for 26 hr at 20°C.

Curves *F* and *G* (Fig. 7) were obtained on wires that were annealed 1½ hr at 285°C, chemically brightened, and then oxidized in air under the con-

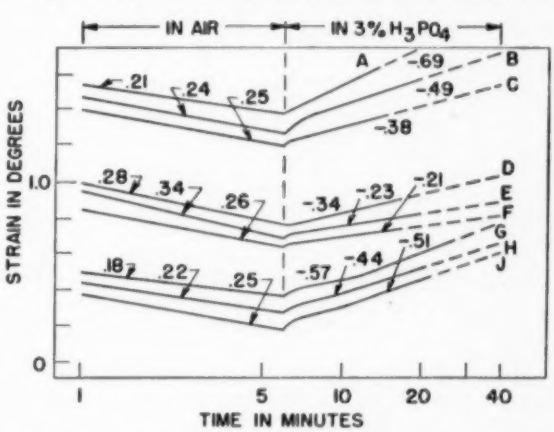


Fig. 8—Effect of pretreating a 5 v chromic acid anodic film in distilled water. The results are given in triplicate. *A,B,C:* Standard 5 v film without pretreatment. *D,E,F:* Pretreated 1 hr in water at 20°C. *G,H,J:* Pretreated ½ hr in water at 100°C.

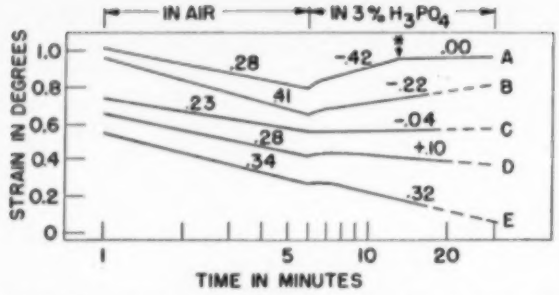


Fig. 9—Effect of pre-etching a 5 v chromic acid film on the strain rates in air and in 5 pct phosphoric acid. *A*—No pre-etch. *Reagent changed to distilled water. *B*—Pre-etched 2 min in 3 pct H_3PO_4. *C*—Pre-etched 15 min in 3 pct H_3PO_4. *D*—Pre-etched 32 min in 3 pct H_3PO_4. *E*—Pre-etched 9 min in 3 pct NaOH.

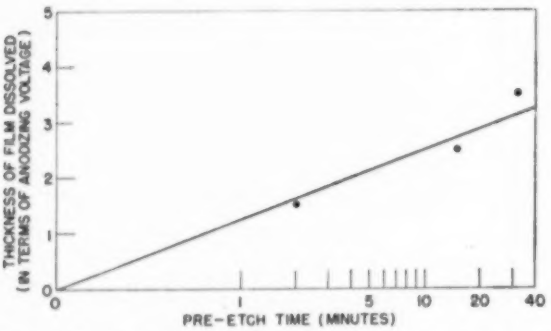


Fig. 10—Rate of attack of an anodic chromic acid film by 3 pct H_3PO_4.

ditions shown. The thickness of the natural oxide film formed in air at room temperature lies in the range from 10 to 100Å.[5, 6] Growth of a film is more rapid and its thickness much greater when formed in air at higher temperatures, but comparison of curves *F* and *G* suggests that despite its greater thickness a high temperature film is no more effective in causing dislocations to pile up beneath the film than is an air-formed film, owing, presumably, to less adherence to the metal, or to a greater tendency to crack during twisting and to let dislocations escape. The wire tested in curve *H* was chemically polished and immediately submerged in distilled water for 26 hr. The film formed by this treatment has an effect similar to the air-formed film.

The effect of distilled water on anodic films is reported in Fig. 8. The films were prepared as before on wires annealed 1½ hr at 285°C and chemically polished; anodizing was in a 3 pct chromic acid bath with potential of 5 v. Curves *D*, *E*, and *F* compared with *A*, *B*, and *C* show that 1 hr distilled water at 20°C before twisting reduces the change in strain rate that occurs when 3 pct phosphoric acid is applied to the film. This may be accounted for by solvent action in the water together with a partial conversion of the layer to weaker or less adherent material. Some beta-trihydrate[3] is doubtless produced, as this is commonly found as a corrosion product when aluminum stands in water. A change in volume accompanying the transformation may also contribute to the weakening.

Curves *G*, *H*, and *J*, giving the effect of a 30 min treatment in distilled water at 100°C, which should produce some alpha-monohydrate in the coating,[3]

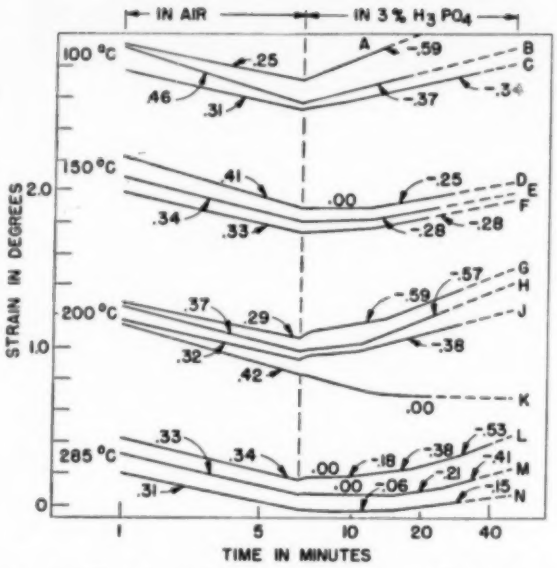


Fig. 11—Effect of annealing 5 v chromic acid anodic film at various temperatures in air. The results are given in triplicate for each annealing temperature. The strain rates for each curve are given in the figure.

resemble curves *A*, *B*, and *C* for the untreated films. The marked change that occurred with the sealing of a sulphuric acid film (Fig. 7) was not duplicated in these experiments on the chromic acid films.

The results of pre-etching are shown in Fig. 9. Wires that had been annealed 1½ hr at 285°C, chemically polished and anodized (3 pct chromic acid, 5 v) were etched for various times in 3 pct phosphoric acid before twisting. The change in strain rate on changing from air to 3 pct phosphoric acid becomes less as the time of pre-etching increases (curves *A*, *B*, *C*, *D*). These results indicate a gradual thinning or weakening of the film. An approximate idea of the effective thickness left after pre-etching for different times in terms of anodizing voltage to produce an equivalent film can be obtained from the curve of rate in 3 pct phosphoric acid, Fig. 3. If the effective film-thickness dissolved is plotted against the logarithm of the time of etching, a straight line is approximated as shown in Fig. 10. Curve *E* indicates that 9 min in 3 pct NaOH is more than sufficient to remove the film.

The change from 3 pct phosphoric acid to water in curve *A*, Fig. 9, as well as the curves of Fig. 6, suggests that the strain rate immediately after a wire with a standard type of film is immersed in one of these reagents is directly related to the rate of attack of that reagent on the film and that a quantitative comparison of rates of attack by different reagents may be had from such tests.

Fig. 11 records the results of annealing anodic films. Wires were annealed, polished, and anodized as in the previous experiments and the anodized wires were then annealed for 1 hr at a series of temperatures. Annealing at 100°C appears to have no deleterious effect on the strength of the film and therefore probably does not cause any changes in the film (curves *A*, *B*, *C*). With annealing above 100°C the change in strain rate in 3 pct phosphoric acid increases after periods of immersion of about

6 min, and similar changes are somewhat more pronounced in films annealed at 285°C. It is presumed that thermal stresses cause the formation of a network of cracks in the anodic film and that at the base of these cracks rapid oxidation will occur. It appears that the furnace-formed oxide under the cracks is attacked at a different rate than the anodic film, so that the rate of untwisting in acid undergoes unusual changes. Since the final slopes of curves *D* to *N* vary considerably, it is concluded that there is a wide variation in the degree of alteration of the anodic films during annealing, as might be expected if a rather limited number of crack systems were developed.

Summary

The abnormal after-effect in twisted wires that occurs when untwisting is interrupted by etching can be used to give quantitative information regarding surface films on the wires, if the following variables are controlled: cold work, recovery, recrystallization, and grain growth in the metal prior to twisting; magnitude and duration of the twisting; duration of the initial untwisting prior to etching; nature, temperature, and concentration of the etchant; length and diameter of the wires.

This method was applied to high purity aluminum with various oxide and anodic coatings. The abnormal effect is much greater with the thick, porous type anodic films than with the thin, dense type produced in boric acid or with films formed in air or water, and increases with increasing anodic film thickness. The *normal* after-effect rate, however, is independent of this thickness. The rates of attack on a chromic acid anodic film by several different reagents were studied, using as an index the change of rate of untwisting when an etchant is applied. A 2 pct boric acid plus 0.25 pct ammonium hydroxide solution showed the slowest rate of attack, while solutions of sodium hydroxide and of ammonium hydroxide showed the fastest attack among those tried. Adding 2 pct chromic acid to 3 pct phosphoric acid slowed its attack. The rate of attack by water was not altered by adding a wetting agent or by adding ethyl or methyl alcohol.

Sealing a porous-type anodic film in 100°C water slowed the attack of dilute phosphoric acid, but similar treatment in 5 pct $K_2Cr_2O_7$ or in 0.001 normal HNO_3 was relatively ineffective. Annealing anodic films at 100°C in air did not alter their properties, but changes were introduced by annealing at 150° to 285°C.

Acknowledgment

This work was supported in part by Contract N-6ori-02004, U. S. Office of Naval Research.

References

[1] C. S. Barrett: *Acta Metallurgica* (1953) **1**, p. 1.
[2] C. S. Barrett: This issue, p. 1652.
[3] F. Keller and S. D. Edwards: Pittsburgh International Conference on Surface Reactions (1948) p. 202.
[4] H. H. Podgurski: Quoted in ref. 3.

Technical Note

Surface Structures on Single Crystals Produced from Melt

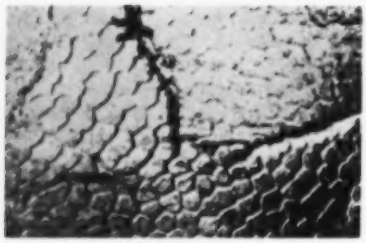
by F. D. Rosi

IN the production of single crystals by the Bridgman method of solidification from the melt in vacuum at a crucible lowering rate of 0.25 in. per hr, a cellular structure was frequently observed in copper and copper-base alloys at the terminal surface of the as-cast crystals (i.e., the surface representing the last portion of the crystal to solidify). The geometrical form of this structure varied from crystal to crystal, but, in general, could be classified as either hexagonal or quadrilateral. Fig. 1 shows examples of this cellular structure, which is similar to that reported by Buerger[1] and, more recently, by Pond and Kessler[2] and Rutter and Chalmers.[3] In the micrographs of Figs. 1b and c, the cubic structure in the alloy crystals is obscured somewhat by excessive surface evaporation in the final stages of solidification.

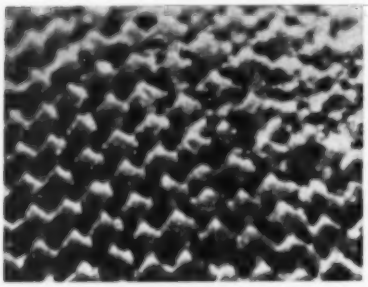
X-ray orientation studies indicate that the traces outlining the various geometrical forms correspond to octahedral planes, which are the planes of greatest reticular density in the face-centered cubic lattice. It would appear from this that the view first propounded by Bravais,[4] that the surface energies and normal growth velocities of the different crystal planes are inversely proportional to their reticular densities, applies to this cellular structure, since those surviving are the planes of greatest atomic density. Thus, the observed variation in the geometrical form of this structure in crystals of different orientation is readily understandable from the distribution of the {111} planes in the standard {111}, {110}, and {100} stereographic projections. Depending upon whether the crystal axis (i.e., the direction of crystallization) coincides with a <111>, <110>, or <100> direction, the cellular structure viewed from a surface perpendicular to the crystal axis will consist of a network of regular hexagons, skewed hexagons (with interfacial angles of 110° and 125°), or cubes, respectively. It follows, moreover, that off-orientations from these principal directions will yield modifications of these three basic geometric configurations. In this connection, it is interesting to note that the bounding planes of the hexagonal structure observed in tin by Rutter and Chalmers[3] showed no preferred orientation.

F. D. ROSI, Junior Member AIME, is associated with the Metallurgy Laboratories, Sylvania Electric Products, Inc., Bayside, N. Y.

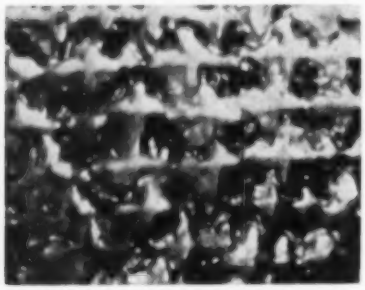
TN 197E. Manuscript, July 20, 1953.



a—Hexagonal structure in spectroscopic (99.999 pct) Cu. Area reduced slightly for reproduction.



b—Cubic structure in Cu-1 atomic pct Si.



c—Cubic structure in Cu-2 atomic pct Ge.

Fig. 1—Transverse cellular structure observed at terminal surface of single crystals. X10.

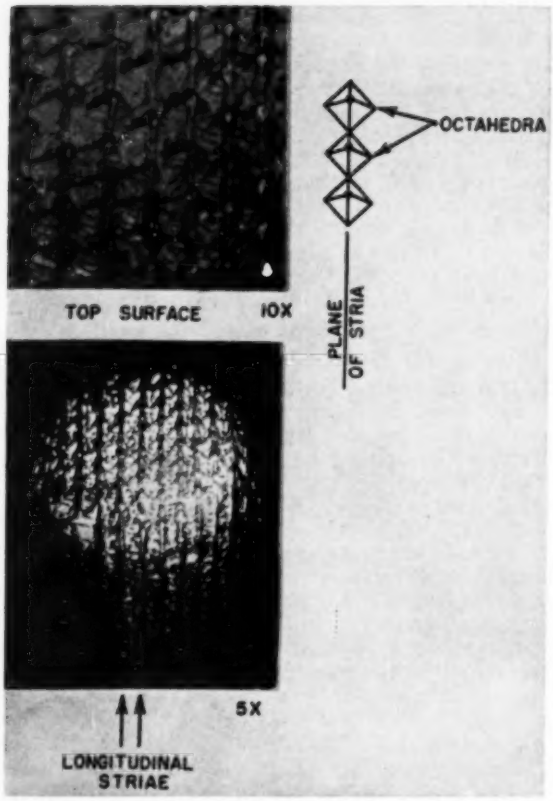


Fig. 2—Relationship between longitudinal line structure with the transverse cellular structure in Cu-2 pct Ge alloy. Area reduced approximately 40 pct for reproduction.

In addition to the transverse cellular structure described above, longitudinal striae were observed which closely resemble the line structure reported by Graf,[5] Pond and Kessler,[2] and Goss and Weintraub.[6] The striae appeared as rather thick lines which were found by X-ray analysis to coincide with {100} planes. Moreover, since only those {100} planes were delineated which made a very small angle with the crystal axis, this line structure was most frequently observed in crystals whose axes corresponded closely to a <100> or <110>.

In agreement with the observations of Smialowski[7] on zinc and, more recently, Goss[6] on single crystals of tin, the longitudinal striae were observed only in the alloy crystals and were considerably enhanced by increasing alloying content. This is in sharp contrast to the cellular structure, which was also observed in crystals of highest purity (99.999 Cu).

In consistency with the established crystallography of both the line and cellular structures, the longitudinal striae were observed to form the diagonals to the cubic pattern of the transverse, cellular structure in the case of a <100> orientation (see Fig. 2), and one of the principal axes of the skewed hexagonal pattern for a <110> orientation.

Acknowledgment

This work is being sponsored in part by the Atomic Energy Commission, Contract AT-30-1, GEN-367.

References

[1] M. J. Buerger: The Lineage Structure of Crystals. *Ztsch. Krist.* (1934) **89**, p. 193.

[2] R. B. Pond and S. W. Kessler: Model for Dendrite Growth Form in Metals and Alloys. *Trans.* AIME (1951) **191**, p. 1156; JOURNAL OF METALS (December 1951).

[3] J. W. Rutter and B. Chalmers: A Prismatic Substructure Formed During Solidification of Metals. *Canadian Journal of Physics* (1953) **31**, p. 15.

[4] A. Bravais: *Etudes Cristallographiques.* (1865). Paris. Gauthier-Villars.

[5] L. Graf: About the Structure of Real Crystal—The Formation of Mosaic Structure in Cast, Plastically Deformed and Recrystallized Materials. *Ztsch. Physik* (1943) **73**, p. 121.

[6] A. J. Goss and S. Weintraub: Growth of Single Crystals of Tin from the Melt. *Nature* (London) (1951) **167**, p. 349.

[7] M. Smialowski: On the Mosaic Structure of Metal Crystals. Wiadomosci. Instytutu Metallurgji i Metaloznowstwa (Warszawa) (1936) **3**, (4), p. 212.

[8] A. J. Goss: Discussion. *Trans.* AIME (1952) **194**, p. 1187; JOURNAL OF METALS (November 1952).

AIME OFFICERS:
President—Andrew Fletcher
Vice-Presidents—T. B. Counselman, L. E. Elkins, O. B. J. Fraser, J. L. Gillson, A. B. Kinzel, J. B. Morrow
President-Elect—L. F. Reinartz
Treasurer and Controller—G. I. Brigden
AIME STAFF:
Secretary—E. H. Robie
Ass't. Secretaries—J. B. Alford, H. N. Appleton, E. J. Kennedy, Jr., Ernest Kirkendall, R. E. O'Brien
Ass't. Treasurer—P. J. Apol

aime NEWS

AIME Annual Meeting Plans Taking Shape

New York Section to be host for 1954 — Meeting program so large that two hotels will be used — All Metals Branch technical sessions to be held at Hotel McAlpin — All other Institute functions scheduled for Hotel Statler

With the Annual Meeting dates, Feb. 15 to 18, 1954, drawing near, plans for the New York gathering are rapidly taking shape. The Hotels McAlpin and Statler will be the center of activity, with metals sessions entirely at the McAlpin.

As usual, there will be a welcoming luncheon, with a well known figure delivering the feature address. One of the outstanding items on the program and of particular interest to Metals Branch members will be the Institute of Metals Div. lecture delivered by Bruce Chalmers. Dr. Chalmers is a professor in the div. of applied science at Harvard University.

The Howe Memorial Lecturer for 1954 will be C. D. King, chairman of the engineering committees of U. S. Steel Corp. He will speak on *Steelmaking Processes—Some Future Prospects.*

Institute of Metals Div. will hold a symposium on semi-conductors, in addition to the regularly scheduled sessions.

The Metals Branch Dinner is scheduled to take place Tuesday evening, and the Extractive Metallurgy Div. luncheon will be held Wednesday. Plans are being arranged for the affairs by the committees responsible. There will also be a Fuels and Combustion Symposium sponsored by the Iron and Steel Div.

Extractive Metallurgy Div.

A tentative program has been outlined by the Extractive Metallurgy Div. Thus far, it is planned to hold morning and afternoon aluminum sessions. Some of the papers to be presented are: *Production of Aluminum-Silicon Alloys from Smelting of Clays and Other Aluminum Silicates; Operation of Experimental Plant for Recovery of Alumina from Anorthosite; Cost Factors in Utilization of Foreign Bauxite; General Prospects and Technology of Using Processed Low-Rank Fuels for Electric Power;* and *The Direct Reading Spectrograph in Aluminum Smelting.*

A copper session will include papers covering: *Hydrometallurgy of Copper-Zinc Concentrate at the Kosaka Smelter; Electrolytic Copper Refinery at Mufulira;* and *Electric Furnace Melting Practice at Canadian Copper Refiners, Ltd.*

A hydrometallurgy-physical chemistry session will include: *Galena Oxidation in Aqueous Solution; Treatment of Uranium Ores by Basic Pressure Leaching and Hydrogen Precipitation; Fundamentals of Agitation and Applications to Extractive Metallurgy;* and *Some Factors Affecting the Structure of Zinc Electrodeposits.*

Lead-zinc papers thus far decided upon are: *Continuous Vacuum Dezincing of Lead Bullion; The Desilverizing of Lead Bullion; Thoughts on Lead Blast Furnace Practice;* and *Operation of the Midvale Dwight-Lloyd Sintering Plant* and *Lead Blast Furnaces on a Two-Shift Basis.*

A joint session with the Minerals Beneficiation Div. on hydrometallurgy and solution and precipitation processes is on the schedule. Papers to be heard will include: *Electrolytic Production of Hydrometallurgical Reagents for Processing Manganese Ores; Operations of the Sherritt Gordon Pilot Plant; Specific Data on Ion-Exchange in the Metallurgical Industry;* and *Continuous Ion Exchange.*

One session dealing with lead, zinc, and cadmium will have papers dealing with: *Additional Information Regarding the Conditioning of Vapors from Electrothermic Zinc Furnaces; Fluid Bed Roasting Process; Fluidity of Lead Blast Furnace Slags;* and *Vacuum Distillation of Silver-Bearing Crusts.*

The second session covering physical chemistry of extractive metallurgy is scheduled to hear reports on: *The Vapor Pressure of Zinc Sulphide from 680° to 825°C; Determination of the Standard Free Energy of Formation of Zinc Sulphide and Magnesium Sulphide; Improved Vacuum-Fusion Method for the Determination of Oxygen and Nitrogen in Metals;* and *Theoretical Analysis of Diffusion of Solutes During the Solidification of Alloys.*

A third in the series of the physical chemistry of extractive metallurgy may encompass such papers as: *The System Ag_2O-B_2O_3: Its Thermodynamic Properties as a Slag Model; The Liquid System NaCl-$ZrCl_4$: Vapor Pressure and Liquidus; Exchange of Antimony Between Molten Antimony and Fused Antimony Oxide; Fuming of Zinc from Lead Blast Furnace Slags—A Thermodynamic Study;* and *Activities in the Lime-Silica-Iron Oxide System.*

Morning and afternoon symposiums will cover arc-furnace copper melting. Thus far, one paper on *Calcium Metal: Laboratory Preparation by Vacuum Metallurgy,* has been lined up for the session on uncommon metals. However, other papers are expected on silicon and the separation of rare earth metals by ion exchange.

Women's Auxiliary Plans

Women's Auxiliary plans include several theater parties. Among the shows that can be seen by the ladies are: Comedy in Music, Golden Theater; Dial M for Murder, Plymouth Theater; Guys and Dolls, 46th Street Theater; Me and Juliet, Majestic Theater; My Three Angels, Morosco Theater; Picnic, Music Box; South Pacific, Broadway Theater; Take a Giant Step, Lyceum Theater; The King and I, St. James Theater; The Seven Year Itch, Fulton Theater; Wonderful Town, Winter Garden; and Tea and Sympathy, Ethel Barrymore Theater. Those who wish to attend the shows should write well in advance directly to the theaters listed.

Nominating Committee for AIME Officers, 1955

The following have been named by the Council of Section Delegates, the Branch Councils, and the President of the Institute to constitute the Nominating Committee for AIME Officers in 1955. The Committee will meet during the Annual Meeting of the Institute in New York, Feb. 15 to 18, 1954 and select the official slate. If the principal finds it impossible to attend, the alternate will act in his place; otherwise the alternate will not be present at the meeting of the Committee. The names of alternates are given in parentheses.

Mining Branch Council: A. B. Cummins, Johns Manville Co. Research Center, Manville, N. J. (R. M. Foose, Dept. of Geology, Franklin & Marshall College, Lancaster, Pa.); R. E. Byler, The Merrill Co., 582 Market St., San Francisco 4, Calif. (Will Mitchell Jr., Allis-Chalmers Mfg. Co., P. O. Box 512, Milwaukee 1.

Metals Branch Council: T. D. Jones, American Smelting & Refining Co., Barber, N. J. (Walter A. Dean, Aluminum Co. of America, 2210 Harvard Ave., Cleveland, Ohio.)

Petroleum Branch Council: Paul Turnbull, Wilson Tower, Corpus Christi, Texas. (R. W. French, Jr., Sohio Petroleum Co., 1300 Skirvin Tower, Oklahoma City, Okla.)

Council of Section Delegates, Executive Committee: Fred J. Meek, American Zinc Co. of Illinois, Box 495, E. St. Louis, Ill. (Roy Sullins, Humble Oil & Refining Co., Box 626, New Orleans 7, La.)

New York Section: John H. Ffolliott, Miami Copper Co., 61 Broadway, New York 6, N. Y. (G. Howard Le Fevre, U. S. Smelting Refining & Mining Co., 57 William St., New York 5, N. Y.)

Detroit Section: Richard D. Chapman, Chrysler Corp., Box 1118, Detroit 31, Mich. (Frederick P. Bens, Climax Molybdenum Co., 14410 Woodrow Wilson Ave., Detroit 3.

Philadelphia Section: F. J. Dunkerley, 247 Engineering Bldg., University of Pennsylvania, Philadelphia, Pa. (F. B. Litton, Foote Mineral Co., P. O. Box 576, Berwyn, Pa.)

Florida Section: J. L. Weaver, American Cyanamid Co., Brewster, Fla. (Felix J. Losson Jr., 1400 Lake Bonny Drive, Lakeland, Fla.)

Central Appalachian Section: Veleair C. Smith, Kanawha Valley Bldg., Charleston, W. Va. (George E. Keller, Commercial Testing & Engineering Co., Charleston, W. Va.)

Nevada Section: John C. Kinnear Jr., Kennecott Copper Corp., McGill, Nev. (Vernon E. Scheid, Mackay School of Mines, Reno, Nev.)

Wyoming Section: M. O. Hegglund, 1974 S. Cedar St., Casper, Wyo. (B. W. Allen, Ohio Oil Co., P. O. Box 120, Casper Wyo.)

Southern California Section: John S. Bell, Humble Oil & Refining Co., 612 S. Flower St., Los Angeles 17.

Permian Basin Section: Jack M. Moore, Dowell Inc., P. O. Box 1858, Midland, Texas. (James C. Blackwood, Amerada Petroleum Corp., P. O. Box 312, Midland, Texas.)

North Texas Section: Rollie P. Dobyns, U. S. Bureau of Mines, Box 612, Wichita Falls, Texas. (R. B. Gilmore, DeGolyer & MacNaughton, 5625 Daniels Ave., Dallas, Texas.)

President Fletcher's appointments: Grover Holt, Cleveland-Cliffs Iron Co., Hibbing, Minn. (Walter Penick, Western Precipitation Corp., San Francisco.) Edward G. Fox, Philadelphia & Reading Coal & Iron Co., Philadelphia, Pa. (W. W. Everett, Glen Alden Coal Co., Wilkes-Barre, Pa.); John Golden, U. S. Steel Corp., Pittsburgh, Pa. (T. S. Washburn, Inland Steel Co., Chicago, Ill.)

Members of the Institute are invited to write to the Chairman, or any or all members of the Committee, suggesting the name of a candidate for President-Elect for 1955, a Vice-President, or a Director. One President-Elect is to be named, two Vice-Presidents, and six other Directors.

1954 Publications' Policies Established

Pursuant to Article X of the bylaws of the AIME, the following information is hereby given as to the "conditions, prices, and terms under which the various classes of Members, and Student Associates, severally, shall be privileged to obtain publications of the Institute during the ensuing year."

Publications authorized for issue in 1954 include the following: MINING ENGINEERING, published monthly, containing material, including technical papers, of interest to those engaged in exploration, mining geology and geophysics, and metal, nonmetallic, and coal mining and beneficiation, and fuel technology. The JOURNAL OF METALS, published monthly, containing material, including technical papers, of interest to those engaged in nonferrous smelting and refining, iron and steel, and physical metallurgy. The JOURNAL OF PETROLEUM TECHNOLOGY, published monthly in Dallas, containing material, including technical papers, of interest to those engaged in petroleum and natural gas drilling and production.

Annual subscriptions to any one of the above journals will be provided all Members in good standing without further charge. (A Member ceases to be in good standing if current dues are not paid by April 1). If more than one of the monthly journals is requested, $4 extra will be charged for an annual subscription, or 75¢ for single copies of regular issues and $1.50 for special issues. The nonmember subscription price for each journal is $8 in the Americas; foreign, $10, and for single issues $1 for regular issues and $2 for special issues. Student Associates will be entitled to the same privileges for all publications as Members. AIME Members subscribing to more than one of each of the three monthly journals will be billed at the nonmember rate of $8 per year, domestic; $10 foreign, for the extra subscription(s).

Three volumes of *"Transactions"* are authorized for 1954 publication, as follows: No. 196, Mining Branch; No. 197, Metals Branch; and No. 193, Petroleum Branch. These volumes will be available to Members at $3.50 each for a first copy if paid for in advance with dues; otherwise at the nonmember rate of $7 less 30 pct. Nonmembers $7 in the United States; foreign $7.50.

Special volumes now planned for publication in 1954 include the following: 1—*Open Hearth Proceedings*, Vol. 37, price to AIME Members $7; nonmembers, $10. 2—*Blast Furnace, Coke Oven, and Raw Materials Proceedings*, Vol. 13, AIME Members $7; nonmembers $10. 3—*Electric Furnace Steel Proceedings*, Vol. 11, AIME Members $7; nonmembers $10. 4—*Dislocations in Metals*, $5. 5—*Statistics of Oil and Gas Development and Production*, Vol. 8, covering data for the year 1952, Members $5, nonmembers $10. 6—*Index to AIME Petroleum Publications*, 1900 to date, $7 less 30 pct discount to AIME Members. 7—AIME *Directory and Yearbook*, free to Members. 8—Reprint of *Ore Deposits of the Western States* (Lindgren volume), price to be announced.

If dues are paid subsequent to January 31, back issues of Institute publications will be supplied only if adequate stocks are on hand. A member may not receive a volume of *"Transactions"*, or a special volume, in lieu of a monthly journal, free of charge on membership. Members in arrears for dues are not entitled to special Members' prices for publications.

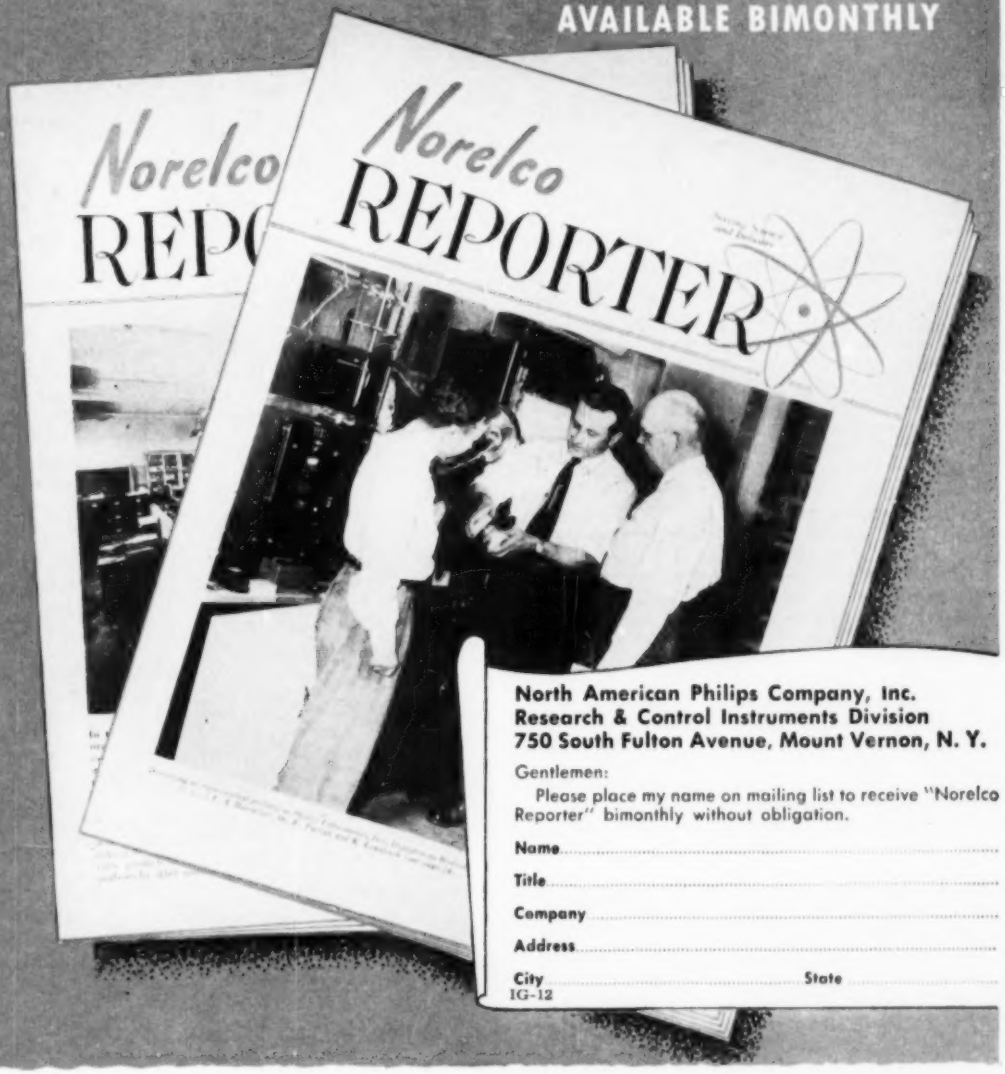
Rocky Mountain Members may have their choice of an annual subscription to one of the monthly journals on request.

AIME Dues Bills in Mail

Pursuant to Article II, Section 2, of the bylaws of the AIME, notice is hereby given that dues for the year 1952 are payable Jan. 1, 1954, as follows: Members and Associate Members, $20; Junior Members for the first six years of Junior Membership, $12 and thereafter, $17; Student Associates (including an annual subscription to a monthly journal), $4.50.

Dues bills were mailed early in November. Prompt payment will assure uninterrupted receipt of the publications desired in 1954. If, for any reason, a bill is not received within a reasonable time, headquarters should be notified.

FOR APPLICATION AND PRODUCT DEVELOPMENT NEWS IN
X-RAY INSTRUMENTATION AND ELECTRON MICROSCOPY
Send for your FREE COPY—
AVAILABLE BIMONTHLY



North American Philips Company, Inc.
Research & Control Instruments Division
750 South Fulton Avenue, Mount Vernon, N. Y.

Gentlemen:

Please place my name on mailing list to receive "Norelco Reporter" bimonthly without obligation.

Name.....

Title.....

Company.....

Address.....

City..... State.....

IG-12

A Norelco PRODUCT NORTH AMERICAN PHILIPS COMPANY, INC.

Serving Science and Industry

Dept. IG-12 · 750 South Fulton Avenue, Mount Vernon, N. Y.

In Canada: Rogers Majestic Electronics Ltd., 11-19 Brentcliffe Road, Leaside, Toronto 17, Ontario

Sessions on Recrystallization, Titanium, Research In Progress, Highlight IMD Fall Meeting

Cleveland Section Plays Host at Cocktail Party and Banquet.

IMD Chairman Morris Cohen presided at the Executive Committee meeting and served as Toastmaster at the Annual Dinner.

An all day Titanium Symposium, an evening Panel Discussion on Recrystallization, two Research in Progress Sessions, as well as the regular sessions drew 782 registrants to the IMD Fall Meeting in Cleveland. All sessions were well attended and the program was so arranged that everyone could find something in his field of interest.

M. A. Hunter, Rensselaer Polytechnic Institute and J. H. Jackson, Battelle Memorial Institute served as Chairmen at the Titanium Symposium. B. L. Averbach acted as Moderator on the Recrystallization Panel.

From the time it was scheduled, the evening Panel Discussion on Recrystallization generated much interest. To assure an accurate account of the proceedings, C. S. Barrett, University of Chicago, was prevailed upon to report his views of the session for JOURNAL OF METALS. The following is Dr. Barrett's report:

"The evening session devoted to a panel discussion of recrystallization set a record in attendance and in number of facts presented by the speakers, but somehow it was a bit lacking in audience appeal.

"There was found to be an unexpected atmosphere of agreement on basic ideas concerning recovery and recrystallization. There was no *minority group* that objected to the proposals of the other panel members, and in fact there was almost no controversy. It was agreed that low energy sub-boundaries are subject to subgrain growth and that, just as with ordinary grains, the growth of these could be either of the normal or abnormal (secondary recrystallization) type. Recrystallization consists of the migration of boundaries of the high angle, high energy type through the mosaic pattern of subgrains, erasing them, but certain of the properties may have changed before this occurs. Dave Turnbull mentioned that the heat of activation for this boundary migration was, in general, a quantity that depended upon temperature rather than being a constant. Cyril Smith suggested that the atom vacancies that were highly dispersed and therefore *in solution* after cold-working a metal tend to coalesce—to *precipitate*—and thereafter serve to pin down the subgrain boundaries that contact them, though not the high-angle boundaries. The recrystallization process as stated in A. H. Cottrell's new monograph, *Dislocations and Plastic Flow in Crystals*, seemed to summarize reasonably well the current thought in this country as well as in Britain.

"The panel members' reviews of what goes on during recovery and before recrystallization were instructive. Some calorimetric tests have shown that the major part of the residual energy from cold work comes out prior to recrystallization, yet others have shown that energy comes out both before and during recrystallization. E. E. Stansbury pointed out that the recent tests on copper by Paul Gordon clearly correlate the major part of the energy release with the progress of recrystallization, but this appears not to be true of metals in general. Ben Averbach pointed out that an analysis of X-ray diffraction lines seemed to indicate that the residual energy could be ascribed to the energy of the subgrain boundaries, but not to the strains within the subgrains. (In one case mentioned, 400A subgrains might account for about 0.2 cal per g, whereas the strains determined by X-rays would only store up about 0.04 cal per g.)

"Paul Beck, Robert Maddin, and Joe Burke discussed the question of whether recrystallization textures can be accounted for by oriented nucleation or by oriented growth. Now

Above, Walter Dean and Dick Chapman discuss one of the items at the IMD Executive Committee meeting, while at the right, John Nielsen, Michael Bever, and T. A. Read concentrate over a problem.

here is a question that can usually be counted on to stir up some heated controversy. Yet it turned out that here, too, there appeared to be general agreement among the experts: Oriented growth was a major factor; oriented nucleation might or might not be important, and dogmatic opinions were not being offered from the platform. Actually, differences of opinion certainly did exist, but perhaps the lateness of the hour accounted for their being de-emphasized.

"By this time the audience, which was a very large one in a very uncomfortably warm room, began to feel that the level of insipidity was getting definitely too high. If something was not done quickly there would be a stampede for the beer so tantalizingly close at the back of the room. One of the listeners tried to needle the speakers into less cautious statements that might stir up a scrap, but without success. Then when one or two of the audience tried to get some free consulting services out of the experts with detailed questions on problems that were bothering them at the moment, that did it! The rear half of the room had rushed the beer before the Chairman could get to a microphone to declare the meeting adjourned.

"The rest of the evening was a social success of the first magnitude and conversation never lagged. Not a little of it was debate on whether a different topic would have been better, maybe one about which there is less knowledge and more speculation. Perhaps a *Meet the Press* would work, though it seems obvious that while a grilling can make desirable headlines for a politician, it could easily make both victim and audience miserable in metallurgical circles. Perhaps merely a change of rules would add spirit to the affair: No talks or answers that are long enough to *present a paper* either of the research type or the review type; more audience participation; no questions that are not of interest to at least a sizable portion of the audience."

AIME officers present at the Fall Meeting were Vice-President O. B. J. Fraser, President-Elect Leo Reinartz, shown above, and Vice-President A. B. Kinzel.

The Annual Dinner Tuesday evening was preceded by a cocktail party sponsored by the Cleveland Local Section of AIME. Morris Cohen, IMD Chairman, served as Toastmaster, and thanked the Cleveland Section for their efforts that resulted in the highly successful meeting. He introduced Vernon Kalan, Chairman of the Section, who acknowledged the help of the various industries in Cleveland in sponsoring authors' breakfasts. Mr. Kalan introduced his committee members, and then paid tribute to the late Prof. Ken Donaldson of Case Institute of Technology, who had been an outstanding AIME supporter. He went on to relate some of the accomplishments of the Section, not the least of which was the preparing of a television program promoting engineering. The program was produced last February, and another will be produced this coming February. Any local section interested in this activity would do well to contact the Cleveland Section. They have found that 60 hr preparation is needed for a ½ hr program.

Morris Cohen then introduced Jack Scaff, Chairman-Elect, IMD; AIME Vice-Presidents O. B. J. Fraser and A. B. Kinzel; Prof. Culver; E. O. Kirkendall. Ralph Wilson, ASM President, addressed the group briefly, pointing out that this was the 27th year of AIME cooperation with ASM in the Metals Congress. AIME President-Elect Leo Reinartz then gave an interesting address, talking in turn about the Institute, IMD, and the role of metallurgists in industry.

At the conclusion of the dinner, Prof. H. Alyea, Princeton University, proceeded to give his excellent talk on "Atomic Energy: Weapon for Peace." His rapid fire method of speaking, the physical effort he expends in putting his ideas across and performing his experiments, keep an audience at the edge of their seats for 1 hr 40 min and makes it seem like a short time. It was estimated that it would take the average person approximately twice as long to present the same material, and would be nowhere as interesting.

Registrants listen intently to the paper being presented at the Tuesday afternoon Research in Progress session. Some 12 papers were presented at this session, with over 100 persons in attendance.

AIME Honors For 1954 Announced

At the meeting of the AIME Board of Directors on Nov. 18, the following awards were announced. Presentations will be made at the Annual Meeting of the Institute next February, except as otherwise noted.

Anthony F. Lucas Medal to Bruce H. Sage, Associate Professor of Chemical Engineering, California Institute of Technology, "for his distinguished achievements in research on the phase behavior and thermodynamics of petroleum hydrocarbons; for the development of ingenious techniques and equipment; for the study of these materials under petroleum reservoir conditions; for the resourceful application of mathematics in extending the range of prediction of the behavior of hydrocarbons over a wide range of pressure and temperature; and for his marked contribution to the present-day concepts of good petroleum engineering practice."

James Douglas Medal to W. J. Kroll "for outstanding contributions to nonferrous metallurgy, particularly in the art of lead refining and the production of metallic titanium."

William Lawrence Saunders Medal to Simeon S. Clarke, General Superintendent, Tri-State Mines, Eagle-Picher Co., "for his distinguished abilities as a mining engineer; for his resourcefulness and his genius in adapting modern and in creating new mechanical aids in mining practice; and for his notable contributions to the productivity and the longevity of the Tri-State district."

Charles F. Rand Memorial Medal to Wilfred Sykes, Chairman, Executive Committee, Inland Steel Co.

Erskine Ramsay Gold Medal to Luther C. Campbell, Vice-president, Coal Div., Eastern Gas & Fuel Associates. "Outstanding in his 35 years as engineer, operating official, and executive in the coal-mining industry have been his contributions to mechanization, safety, and the education and welfare of employes."

J. E. Johnson Jr. Award to Robert O. MacFeeters, Assistant Superintendent of Blast Furnaces, Lorain Works, National Tube Div., U. S. Steel Corp. "for the work reported in his paper, *Correlation Between Coke Plant and Blast Furnace Operations* and his other contributions to the knowledge of blast furnace operation."

Robert H. Richards Award to C. Harry Benedict "for his pioneering achievement in the treatment of native copper ores and a half century of faithful service to his profession."

Percy Nicholls Award to Henry F. Hebley, Research Consultant to the Pittsburgh Consolidation Coal Co. "As a Fellow of the ASME and as Chairman of its Fuels Div. in 1943, and also as Chairman of the Coal Div. of the AIME in 1946, he has been especially active in promoting the aims of both societies in the field of solid fuels. His early interest in combustion and in the preparation and sampling of coal has resulted in many important contributions to the technical knowledge of those subjects. His recent activities in the control and prevention of both air and stream pollution are of outstanding value, both to his fellow engineers and to the public at large." (Awarded jointly by the Coal Div., AIME, and the Fuels Div., ASME, at the Fuels Conference, Oct. 29, 1953.)

Robert W. Hunt Medal and Award to J. B. Wagstaff, J. F. Elliott, and R. A. Buchanan for their paper entitled, *Physical Conditions in the Combustion and Smelting Zones of a Blast Furnace*, published in the JOURNAL OF METALS, July 1952. Messrs. Buchanan and Wagstaff are associated with the research laboratory of the U. S. Steel Co., and Mr. Elliott is with the Inland Steel Co.

Mathewson Gold Medal to E. S. Machlin, Assistant Professor, School of Mines, Columbia University, and Morris Cohen, Professor of Physical Metallurgy, Massachusetts Institute of Technology, for a series of three papers: *Burst Phenomenon in the Martensite Transformation* (JOURNAL OF METALS, Sept. 1951); *Habit Phenomenon in the Martensitic Transformation* (Nov. 1951); and *Isothermal Mode of the Martensite Transformation* (May 1952).

Rossiter W. Raymond Award to Stanley F. Reiter, Research Associate, General Electric Co., for his paper, *Recrystallization Kinetics of Low Carbon Steel* (JOURNAL OF METALS, Sept. 1952).

Howe Memorial Lecturer, 1954, C. D. King, Chairman, Engineering Committee, U. S. Steel Corp.

Institute of Metals Division Lecturer, 1954, Bruce Chalmers, Professor of Metallurgy, Harvard University.

Jackling Lecturer, 1954, Reno H. Sales, Chief Geologist, Anaconda Copper Mining Co.

W. W. Staley Addresses Columbia Local Section

Professor W. W. Staley of the School of Mines, University of Idaho, spoke to the Columbia Section at Spokane, Wash. on October 20. Professor Staley, who is past Chairman of the Columbia Section, related his experiences in the Philippines where he went to set up a mining school at the request of the Mutual Security Agency. AIME Members from Colville, Wallace, Kellogg, Moscow, and Pullman attended the meeting.

Philadelphia Section Awards Student Prizes

The annual student paper night of the Philadelphia Section was held at the University of Pennsylvania on October 15. First and second prizes for the undergraduate papers were awarded to Herman S. Rosenbaum and George J. Binczewski respectively. Harry Green was awarded the first prize for graduate papers. After medals and certificates had been awarded to the students, Mr. Rosenbaum presented his paper.

Institute Names 1954 Legion of Honor

Each year, at the Annual Banquet in February, those members of the AIME who have continuously maintained their membership for 50 years are given special recognition. They are seated at the head table as guests of the Institute and are added to the membership of the Legion of Honor. The list appears on page lxvi of the current Directory, and the names of those who will achieve this status in 1954 are as follows:

Blow, John J.
Barbados, B. W. I.
Boutwell, John M.
Salt Lake City, Utah
Boynton, Arthur J.
Chicago, Ill.
Brooks, John M. Jr.
El Paso, Texas
Bryant, George W.
Los Angeles, Calif.
Cates, Louis S.
New York, N. Y.
Channing, R. H.
New York, N. Y.
Cobb, H. McL.
Guanacevi, Dgo., Mexico
Dakin, Frederick H.
Burlingame, Calif.
Fohs, F. Julius
Houston, Texas
Goodale, Stephen L.
Pittsburgh, Pa.
Guernsey, F. W.
Vancouver, B. C., Canada
Hunter, H.
Tokyo, Japan
Jones, Charles H.
Forfar, Scotland
Lindsay L.
Chichester, England
Mills, Edwin W.
Salome, Ariz.
Paymal, George W.
Altadena, Calif.
Pelton, Roger T.
La Jolla, Calif.
Posada, Juan de la C.
Antioquia, Colombia
Prout, John W., Jr.
Beverly Hills, Calif.
Schroter, George A.
Brooklyn, N. Y.
Swanquist, G. A.
El Salvador, Central America
Wright, Louis A.
Palo Alto, Calif.

Research Group Submits Report

The 12th progress report of the Engineering Foundation Project on Diffusion in Steel has been released by Mórris Cohen of M.I.T. The research consists of a long range study of diffusion kinetics in steel, starting with the basic problem of self-diffusion in high purity iron.

Correlation between diffusion rate and strain rate has been confirmed using temperatures in the range of 825° to 890°C for alpha iron. However, it is not yet clear whether strain per se (as distinct from strain rate) is an important factor. The self-diffusion measurements near the Curie point completed on high-purity iron tends to confirm the anomaly in the diffusion rate at the Curie point. High-purity iron titanium alloys prepared by the National Research Corp. have been fabricated into diffusion couples and tests are under way.

The work is being conducted by Vernon Griffiths, assisted by Vladimir Czerniszow at the Massachusetts Institute of Technology. These men operate as a part of a larger research group devoted to the general study of diffusion in metals.

A. S. Cohan Appointed Manager of Publications

After completing a most satisfactory tenure of six months as Acting Manager of Publications, Alvin S. Cohan has been named Manager of Publications, and will serve as Editor of JOURNAL OF METALS as well. He has charge of the publication activities of the Institute in the New York office; petroleum publications will continue to be handled in the Dallas office.

James Head Named 1954 UET President

United Engineering Trustees, Inc., named James L. Head president for the coming year. Mr. Head is a former director of the AIME and has represented the Institute on the UET board since 1947.

A mining engineer with Anaconda Copper Mining Co., Mr. Head is a past president of the Mining and Metallurgical Society of America.

Other officers elected were: Gail F. Moulton of Rockefeller Brothers, Inc., and Walter J. Barrett of New Jersey Bell Telephone Co., vice-presidents; Waldo G. Bowman of McGraw-Hill Publishing Co., treasurer; Joseph L. Kopf of Jabez Burns & Sons, Inc., assistant treasurer; John H. R. Arms, reelected secretary and general manager.

Coming Events

Dec. 1-4, National Assn. of Corrosion Engineers, conference, University of Oklahoma.

Dec. 2, AIME, Chicago Section, Chicago Bar Assn., Chicago.

Dec. 2-4, Mid-Century Conference on Resources for the Future, Washington, D. C.

Dec. 2-4, AIME, Electric Furnace Steel Conference, Netherland-Plaza Hotel, Cincinnati.

Dec. 11, AIME, St. Louis Section, York Hotel, St. Louis.

Dec. 13-16, American Institute of Chemical Engineers, annual meeting, Hotel Jefferson, St. Louis.

Dec. 27, Conference on Scientific Editorial Problems, AAAS, Boston.

Dec. 28-29, Annual Chemical Engineering Symposium, University of Michigan, Ann Arbor.

Jan. 6, 1954, AIME, Chicago Section, Chicago Bar Assn., Chicago.

Jan. 8, AIME, St. Louis Local Section, York Hotel, St. Louis.

Jan. 12-14, National Constructors Assn., annual meeting, Hotel Commodore, New York.

Jan. 13, AIME, Connecticut Section, Bridgeport Brass Co., Bridgeport.

Jan. 13, AIME, Bessemer Committee, annual meeting, Duquesne Club, Pittsburgh

Jan. 20, AIME, National Open Hearth Steel Committee, Western Section, Rodger Young Auditorium, Los Angeles.

Jan. 25-27, Plant Maintenance & Engineering Show and Conference, Hotel Conrad Hilton and International Amphitheatre, Chicago.

Feb. 2, AIME, Chicago Section, Chicago Bar Assn., Chicago.

Feb. 15-18, AIME, annual meeting, Metals Branch, Hotel McAlpin; Mining and Petroleum Branches, Hotel Statler, New York.

Mar. 3, AIME, Chicago Section, Chicago Bar Assn., Chicago.

Mar. 8-10, American Institute of Chemical Engineers, Statler Hotel, Washington, D. C.

Mar. 10, AIME, Connecticut Section, American Brass Co., Torrington, Conn.

Mar. 15-19, National Assn. of Corrosion Engineers, Municipal Auditorium, Kansas City.

Mar. 17, AIME, National Open Hearth Steel Committee, Western Section, Rodger Young Auditorium, Los Angeles.

Apr. 5-7, AIME, Blast Furnace, Coke Oven, Raw Materials Conference, Palmer House, Chicago.

Apr. 5-7, AIME, National Open Hearth Conference, Palmer House, Chicago.

Apr. 7, AIME, Chicago Section, Chicago Bar Assn., Chicago.

Apr. 26-28, Canadian Institute of Mining and Metallurgy, annual meeting, Mount Royal Hotel, Montreal.

Apr. 27, Assn. of Consulting Chemists and Chemical Engineers, Hotel Belmont Plaza, New York.

Apr. 26-30, American Society of Tool Engineers, industrial exposition, Convention Center, Philadelphia.

May 2-6, Electrochemical Society, La Salle Hotel, Chicago.

May 4-7, American Welding Society, national meeting, Hotel Statler, Buffalo.

May 8-14, American Foundrymen's Society, Cleveland Auditorium, Cleveland.

May 16-17, American Institute of Chemical Engineers, Kimball Hotel, Springfield, Mass.

Proposed for Membership

— Metals Branch AIME —

Total AIME membership on Oct. 31, 1953 was 19,503; in addition 1838 Student Associates were enrolled.

ADMISSIONS COMMITTEE

O. B. J. Fraser, Chairman; Philip D. Wilson, Vice-Chairman; F. A. Ayer, A. C. Brinker, R. H. Dickson, Max Gensamer, Ivan A. Given, Fred W. Hanson, T. D. Jones, G. W. Lutjen, E. A. Prentis, Sidney Rolle, J. T. Sherman, F. T. Sisco, R. L. Ziegfeld.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; A, Associate Member; S, Student Associate.

Arizona
Winkleman—Freeman, George A. (R, M)

Connecticut
Wallingford—Cobb, Harold M. (J)

Illinois
Chicago—Golden, Richard M. (J)
Chicago—Reding, John N. (J)
Chicago—Rees, George A. (J)
Chicago—Schiene, Quentin J. (J)
Chicago—Spachner, Sheldon A. (J)
Homewood—Fennell, A. A. (A)

Indiana
Gary—Sorrells, Everett C. (M)

Maryland
Chevy Chase—Melcher, Norwood B. (R, C/S—J-M)
Hyattsville—Pike, Charles S. (R, M)
Hyattsville—Sullivan, Paul M. (J)
Silver Spring—Harris, James C. O. (M)

Massachusetts
No. Dartmouth—Hinman, James H. (M)

Michigan
Trenton—Moyer, Harold W. (M)

Missouri
Ferguson—Henderson, Courtland M. (A)
St. Louis—Potter, Voluntine T. (R, C/S—S-J)

New Jersey
New Brunswick—Weissmann, Sigmund (M)

New York
Brooklyn—Gitto, Joseph J. (J)
New Hartford—Darmara, Falih N. (M)
New York—Hancock, Roy F. (M)
Rego Park, L. I.—Buechner, Robert F. (M)

Ohio
Cleveland—Hallam, Arthur F. (J)
Cleveland—Strindberg, Samuel J. (J)
Columbus—Bara, John A., Jr. (J)
Hamilton—Natwick, John W. (J)
Lakewood—Baskey, Raymond H. (J)
Wyoming—Richman, Roger H. (J)
Youngstown—Beale, John F. (M)

Oregon
Portland—Glover, Clifton (M)

Pennsylvania
Butler—Black, Ray E. (A)
Glenshaw—Pound, Guy Marshall (M)
Lancaster—Meminger, Cyrus H. (M)
Lebanon—Aubrey, W. M., Jr. (M)
Palmerton—Looby, Lawrence F. (J)
Pittsburgh—Crowell, Richard S. (M)
Pittsburgh—Cusick, Arthur C. (M)
Pittsburgh—Kessler, Maxwell M. (R, C/S—J-M)
Pittsburgh—Peterson, Charles E. (A) (R, C/S—S-A)

Washington
Spokane—Folkrod, Clinton B. (M)

Canada
Port Colborne, Ontario—Heron, James B. S. (J)
Windsor, Ontario—Noakes, Gordon E. (J)

TOPS FOR PRODUCTION OF HIGH GRADE STAINLESS, ALLOY AND RIMMING STEELS

Heroult

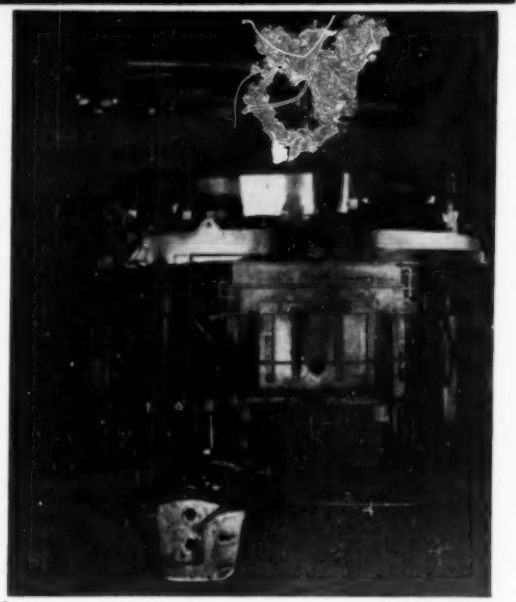
ELECTRIC MELTING FURNACES

EMBODYING the latest in mechanical and electrical equipment, these widely used furnaces are noted for their efficient performance and safety, and low operating cost and maintenance.

We welcome an opportunity to help you select and install the furnace best suited to your particular requirements.

AMERICAN BRIDGE DIVISION, UNITED STATES STEEL CORPORATION
GENERAL OFFICES: 525 WILLIAM PENN PLACE, PITTSBURGH, PA.

Contracting Offices in New York, Philadelphia, Chicago,
San Francisco and other principal cities.
United States Steel Export Company, New York



Removable roof of new design now available for large furnaces.

USS

UNITED STATES STEEL

IT TAKES TOP INSTRUMENTATION TO DO TOP RESEARCH

Whatever your research job, JAco makes instruments that will help you do it faster, more easily and with greater precision. So why handicap your research results with make-do or unreliable equipment — get the JAco Instruments right for your job and see how often difficult jobs become routine.

Recording Comparator Microphotometer
Combines high sensitivity and high linearity with ease of use
3.4 Meter Spectrograph
A completely automatic spectrograph with outstanding resolution and dispersion
Photographic Processing Unit
Self-contained unit for rapid and precise development of film or plates

Write for catalogs

JAco **JARRELL-ASH COMPANY**
26 FARWELL STREET, NEWTONVILLE, MASS.

SALES OFFICES

DETROIT 13680 Capitol Ave. | EL CERRITO, CAL. 1344 Devonshire Drive | CHATTANOOGA 1431 Broad Street | QUEENS VILL., N. Y. 80-56 230th Street

MODERN USES OF NONFERROUS METALS

MODERN USES OF NONFERROUS METALS, edited by C. H. Mathewson, paints on a broad canvas progress in the field of utilization of nonferrous metals. Many radical changes have taken place since the first edition of this book. In essence, this second edition is a completely new work. Every chapter has been rewritten or added to, and in all cases brought up to date. The 26 chapters were written by leading authorities in their fields. Laboratory and production men have made giant strides in developing new alloys to meet man's needs in an ever changing world. Thus, MODERN USES OF NONFERROUS METALS is a work which will find wide acceptance among both technical and nontechnical readers. For the young engineer, it contains a graphic picture of how nonferrous metals are used, while for others it embodies much that is new. The book is written in nontechnical language. Approach in many chapters is narrative. Where illustration is required, tables, graphs, and other devices are used.

$4.90 to AIME Members; $7.00 to Nonmembers

Published through the Seeley W. Mudd Fund by

The American Institute of Mining and Metallurgical Engineers, Inc.,

29 West 39th St., New York 18, N. Y.

Personals

Clarence H. Linder, vice-president and former general manager of General Electric Co.'s major appliance div., was appointed vice-president of engineering and head of the firm's engineering services div. Mr. Linder joined General Electric in 1924 as a student engineer.

James H. Cogshall has rejoined Pennsylvania Salt Mfg. Co. as a sales engineer in the corrosion engineering products dept., Philadelphia. He had served as a lieutenant commander in the Navy.

James W. Cameron has been named works engineer for Basic Refractories, Inc. at the Maple Grove, Ohio quarrying and burning plant operations.

Luther Evans, formerly in charge of industrial relations for the Dow Chemical Co.'s Texas div., has been appointed to the newly created position of director of industrial relations for all Dow operations. Mr. Evans was also recently elected to the board of directors of Dowell, Inc., a subsidiary. He has been with Dow since 1936.

Kurt P. Anderko was appointed as full research metallurgist at Armour Research Foundation of Illinois Institute of Technology, Chicago.

Joe Gin-Young Chow has accepted a position with the Arabian American Oil Co., engineering dept., New York. He had been associated with the Crucible Steel Co. of America in the research laboratory, Harrison, N. J.

W. Monroe Wells, has been named assistant vice-president in charge of operations, Reynolds Metals Co., Louisville. Mr. Wells has been general production control manager with headquarters at Richmond, Va.

William J. Wagnitz, John F. Thompson, Jr., and **Otto W. Langhans,** have been elected to the board of directors of American Platinum Works, Newark.

Frank Lerman, formerly acting supervisor of chemical engineering in the chemistry and chemical engineering dept., has been appointed assistant research advisor at Armour Research Foundation of Illinois Institute of Technology.

P. W. Bakarian is now connected with the titanium div. of the Crane Co., Chicago, Ill.

Frank P. Barton is general manager, lead products div., the G. A. Avril Co., Cincinnati, Ohio. He was formerly with the metallic products div., the Eagle-Picher Co.

A. R. TROIANO

Alexander R. Troiano has been named head of the metallurgy dept., Case Institute of Technology, Cleveland, Ohio. Before coming to Case in 1949, Mr. Troiano was professor and acting head of the metallurgy dept. at the University of Notre Dame.

Max Jaenchen has accepted the appointment of chief consulting engineer for Mannesmann-Meer Engineering & Construction Co., Easton, Pa.

Mark E. Putnam, executive vice-president of the Dow Chemical Co., Midland, Mich., was elected a director of Campbell, Wyant & Cannon Foundry Co.

Stephen Foldes has joined the staff at the Institute for the Study of Metals, University of Chicago, as metallurgist. He had been with the Ford Motor Co., scientific laboratory, Dearborn, Mich.

Marcus Sharp is with the Fruehauf Trailer Co., Detroit.

John G. Dennis is on the staff of the dept. of geology, Columbia University, New York.

Daniel V. Terrett has been elected president of the American Society of Civil Engineers. He is dean of the College of Engineering, University of Kentucky. **Enoch R. Needles** and **Mason G. Lockwood** were named vice-presidents.

LeRoy W. Davis, formerly with the Aluminum Co. of America, Pittsburgh, has joined Kaiser Aluminum & Chemical Corp., Halethorpe, Md., as chief metallurgist.

Roy C. Nichols, formerly with the Diesel equipment div., General Motors Corp., Grand Rapids, Mich., joined the Carboloy dept., General Electric Co., Edmore, Mich.

Dan McLachlan, Jr., and **Bruno J. Zwolinski** have joined the physics staff of Standard Research Institute, Stanford, Calif. They had previously been on the staff of the University of Utah.

William Blum, former chief of the electrodeposition section of the National Bureau of Standards, will be awarded an Elliott Cresson Medal presented by the Franklin Institute for distinguished contributions in the realm of physical sciences.

James H. Bly has been appointed research director for X-Ray Inc., Detroit, Mich. Mr. Bly was formerly supervisor of radiography and electronics in the materials control laboratory of Pratt & Whitney Aircraft.

Alan H. Cottrell, professor of physical metallurgy, University of Birmingham, Birmingham, England, will lecture at various universities in the United States during the fall.

Bernard E. Speranza, metallurgical engineer with General Electric Co.'s chemical and metallurgical training program, joined the Carboloy dept. as an engineer in the carbide materials development section.

Herman A. Brassert resigned as chairman of the board and director of H. A. Brassert & Co., Inc., of New York and is no longer connected with the iron and steel industry.

T. C. Ford is now assistant sales manager of Pittsburgh Metallurgical Co., Inc., at Niagara Falls, N. Y. He was previously with that company in Cleveland, Ohio.

George T. Hahn is no longer a student at Columbia University and is serving as a second lieutenant with the Metals Branch, Materials Laboratory, Wright Air Development, Wright Patterson Air Force Base, Dayton, Ohio.

Morse Hill is now a project engineer with the Brush Laboratories Co., Cleveland, Ohio. He was formerly with National Research Corp., Mahant, Mass.

John T. Richards, formerly with Beryllium Corp., was named president and chief engineer of Penn Precision Products, Inc., Reading, Pa.

James L. Head has been named president of the United Engineering Trustees for the ensuing year, succeeding **R. F. Flagg,** president for the past two years. Mr. Head is a mining engineer with Anaconda Copper Mining Co.

William P. Getty has been appointed assistant vice-president in charge of production and **E. K. Miller** as consultant to the vice-president in charge of production, Jones & Laughlin Steel Corp.

D. D. Barbor is now plant manager of Montana Ferroalloys, Inc., at Memphis, Tenn.

Robert C. Waugh and **Otto P. Eberlein,** both of Cornell University, received first prize in the A. F. Davis Undergraduate Welding Award Program, for their paper *Penetration Factors in Metallic Arc Welding.*

Charles Roebling Tyson was elected a member of the board of directors of Colorado Fuel & Iron Corp., by stockholders at the annual meeting. Mr. Tyson, executive vice-president of John A. Roebling's Sons Corp., served as president of Roebling five years prior to its acquisition by CF&I in 1952.

Clarence E. Jackson, research metallurgist, Metals Research Laboratories, Niagara Falls, N. Y., has been elected vice-president of the New York and New England district of the American Welding Society.

SAMUEL STORCHHEIM

Samuel Storchheim has been promoted to engineer in charge at the Atomic Energy Div. of Sylvania Electric Products Corp., Bayside, N. Y.

John T. McCormack is now with Reynolds Metals Co., Richmond, Va.

John A. Fellows has terminated his association with American Brakeshoe Co. and is now chief metallurgist with the Mallinckrodt Chemical Works, St. Louis, Mo.

Dwayne L. Day is no longer with Battelle Memorial Institute. He is employed by Titanium Metals Corp., at Henderson, Nev.

R. Maddin, associate professor at the Johns Hopkins University will spend 1954 as visiting lecturer in metallurgy in the Dept. of Metallurgy, University of Birmingham, England.

Albert E. Bickell has been promoted to district sales manager of General Refractories Co., and is now with the Philadelphia office.

Ralph A. Happe is now chief metallurgist with Kwikset Locks, Inc., Anaheim, Calif. He was formerly with Battelle Memorial Institute, Columbus, Ohio.

Erwin O. Deimel is now senior research metallurgist, Clayville research dept., Utica Drop Forge & Tool Corp., Utica, N. Y.

Milton C. Reed, formerly with Standard Brakeshoe & Foundry Co., Pine Bluff, Ark., is now chief metallurgist, Dibert, Bancroft & Ross Co., Ltd., New Orleans.

John L. Ham has been appointed director of metallurgical research dept., National Research Corp., Cambridge, Mass.

George R. Harrson, dean of science at Massachusetts Institute of Technology, received an Elliott Cresson Medal from the Franklin Institute.

W. R. Hibbard has retired from the American Brass Co. after 25 years of service in the firm's technical dept. He plans to open a consulting practice in Waterbury, Conn.

Robert N. Randall is now a first lieutenant with the 9th Ordnance Battalion, Fort Bliss, Texas. He moved from Sandia Base, Albuquerque, N. Mex.

W. L. Schalliol, formerly program head, pile fuel div., General Electric Co., is now manager of branches, Northern Indiana Brass Co., Elkhart, Ind.

Robert Eisner is now with the research laboratories of the Westinghouse Electric Corp., East Pittsburgh, Pa.

W. B. Wallis, president of Pittsburgh Lectromelt Furnace Corp., Pittsburgh, has been elected president of the Foundry Equipment Manufacturers Assn., at a meeting held at White Sulphur Springs, W. Va. **D. E. Davidson,** vice-president, sales, Link-Belt Co., Chicago, was named vice president of FEMA. **W. G. Frank,** executive vice-president of American Air Filter Co., Inc.; **Russell J. Hines,** vice-president and general manager of Hines Flask Co., Cleveland, Ohio; and **Odd H. McCleary,** vice-president and general manager of Mathews Conveyor Co., Ellwood City, Pa., were elected to the board of directors of FEMA. **Arthur J. Tuscany, Jr.,** succeeded his father, the late **Arthur J. Tuscany,** as executive secretary.

Lorin L. Ferrall has been appointed assistant vice-president of Crucible Steel Co. **David I. Dilworth, Jr.,** was named director of metallurgy.

George G. Thomas is now a permanent resident of England, living at St. Feock, near Truro, Cornwall.

Ensign R. F. Doelling, CEC, USNR, is serving with the Seabees in a Mobile Construction Battalion overseas.

Calvin R. Cupp is now with International Nickel Co. of Canada, Ltd., research laboratory at Copper Cliff, Ontario.

J. L. Holmquist, director of research, Spang Chalfant Div. of National Supply Co., Ambridge, Pa., received the Kelly Award of the Assn. of Iron & Steel Engineers.

Joseph J. Warga is supervisor, Heat Treating Steel Products Engineering Co., Donnelsville, Ohio.

Robert E. Halloran has been appointed manager of mechanical sales, tubular products div., Babcock & Wilcox Co.

Richard G. Tessendorf was elected a vice-president of Aluminum Industries, Inc., Cincinnati, Ohio. Mr. Tessendorf is a vice-chairman and director of the Aluminum Assn. and a member of SAE.

George H. Tulley has been promoted to sales manager of powdered metals, Metals Disintegrating Co., Cleveland.

Maynard B. Wyman was named engineering and service dept. manager and **H. C. Coleman,** assistant manager, Westinghouse Electric Corp., apparatus div.

Alton W. Bardeen, formerly chief metallurgist of the Ohio Brass Co., succeeds the late **R. W. Parsons** as technical director of the Mansfield plant.

J. R. Van Pelt, president of the Montana School of Mines, Butte, has been appointed to head a survey committee to investigate and analyze the organization and operation of the U. S. Geological Survey.

Philip C. Muccilli, National Lead Co. production manager, has been appointed chairman of the company manufacturing committee.

Walter F. Johnson, American Smelting & Refining Co., has been transferred from Selby, Calif., to South Plainfield, N. J.

Kenneth U. Jenks, secretary and controller of Lindberg Steel Treating Co., was elected a trustee of the Metal Treating Institute.

Hugh V. Allesandroni, manager of research of the technical dept., titanium div., National Lead Co., was promoted to assistant technical director of the div.

Willard F. Rockwell has resigned as assistant to secretary of defense and returned to his position as chairman of the board of directors, Rockwell Mfg. Co.

John E. Caskey has been elected a vice-president of U. S. Rubber Co. and general manager of the company's Naugatuck chemical div.

Appreciation of

Galen Howell Clevenger

by F. S. Mulock

Galen Howell Clevenger (Member 1903) passed away at the Cape Cod Hospital at Hyannis, Mass., on Aug. 2, 1953 after an extended illness.

Though Mr. Clevenger was born in Pike, N. Y., Sept. 1, 1879, much of his early life was spent in South Dakota. He received his B.S. and E.M. degrees from South Dakota State School of Mines in 1901 and 1908, respectively, A.M. from Columbia University in 1903, and Met. E. from Stanford University in 1906.

He was one of the pioneers in the development of the cyanidation process. From 1898 to 1901, while a student at South Dakota, he constructed and successfully operated a plant to treat, by cyanidation, a dump of chlorination tailing adjoining the campus. From 1906 to 1909, he was consulting metallurgist for Charles Butters & Co. Ltd. for its operations in Virginia City, Nev., and San Salvador. From 1909 until 1918 he was successively assistant, associate and research professor of metallurgy at Stanford University. During that period he did extensive research work in connection with all phases of cyanidation as well as along other metallurgical lines in which his associates and students participated, including important work for the Merrill Co., Portland Gold Mining Co., and Nipissing Mining Co. The writer, while instructor in electrical engineering at Stanford, became associated with Mr. Clevenger in 1916 on a research problem for Electrolytic Zinc Co. of Australasia, from which it was first determined that cobalt was an interfering element in the electrodeposition of zinc. The successful outcome of cooperative work conducted in 1917 and 1918 by U. S. Bureau of Mines, Research Corp. of America, and the Dutch East Indies Government on cyanidation of refractory manganese-silver ores, under the direction of Mr. Clevenger and Mr. M. H. Caron, led to a similar study of certain ores of Cia. de Real del Monte y Pachuca and subsequently to Mr. Clevenger's association in 1920 with the parent company, U. S. Smelting Refining & Mining Co., as consulting metallurgist, a position he held until his retirement from active service in 1947. During that period he directed the research work of the company, investigating innumerable problems having to do with all phases of the company's mining, milling, smelting, and refining operations. Without going into detail, suffice it to say that his researches covered a tremendously varied field, his accomplishments were many, and the benefits to the company were great.

An avid reader, Mr. Clevenger always impressed upon his students and those who worked with him, the importance of finding out what others had done. His comment, during discussion of any new problem, of "Let's review the literature," was always expected and always forthcoming. His breadth of knowledge of all phases of metallurgy was phenomenal.

He joined AIME in 1903, was a director from 1920 to 1926, and—until illness overtook him—always was very active in Institute affairs. He was a member of the Mining and Metallurgical Society of America, American Chemical Society, American Electrochemical Society, AAAS, and Sigma Xi, also of the Engineers' Club and Chemists Club of New York, and the Cosmos Club of Washington.

He is survived by his wife, nee Alice Clemens of Centerville, Mass., a daughter Mrs. Thomas F. Burke of West Yarmouth, Mass., a son Galen W. Clevenger of Newtonville, Mass., a brother Henry R. Clevenger of Ashmont, Ark., and four grandchildren.

Those of us who had the good fortune to work closely with Mr. Clevenger have a deep sense of gratitude and appreciation for the knowledge and help which he gave to us so willingly. We, and his many other friends, mourn his passing.

Appreciation of

Lewis Webster Wickes

by Harvey S. Mudd

Lewis Webster Wickes (Member 1902) died at his home in Los Angeles on Sept. 16, 1953. Born at Low Moor, Va. on Aug. 11, 1877, he spent his boyhood days with his parents in Montana at the mining camps of Wickes and Corbin. His mining engineering education was obtained at Massachusetts Institute of Technology, Colorado School of Mines, and Columbia University from which institutions he had degrees of Engineer of Mines and Metallurgical Engineer. He was a member of Phi Kappa Psi. On Feb. 17, 1907 at Ely, Nev., he married Grace Ford. A daughter, Mrs. N. J. Snellenburg of Philadelphia and a grandson, Jonathan, survive.

His early training was varied and broad. He was surveyor and assayer at mines in Colorado and Montana, chemist at the Anaconda Smelter, head chemist at the East Helena plant of American Smelting & Refining Company, field engineer with the U. S. Geological Survey, American Smelting & Refining Co., Gunn-Thompson Co., superintendent of Cumberland Ely Copper Mine and Ely Utah Copper Co. and manager of Nevada Utah Mining & Smelting Co.

During 1905, additional financing for Utah Copper Co. was being sought by Messrs. Penrose and McNeil of Colorado Springs who prior to that time and under the direction of Daniel C. Jackling had carried the burden. Negotiations were carried on with Guggenheim Exploration Co. which undertook a thorough examination of the mine, in the sampling program of which Webster Wickes assisted as the analyst. Following this examination in late 1905, Wickes went to work for George Gunn and W. B. Thompson who were acquiring properties and water rights at Ely, Nev., which later were to be incorporated into the Nevada Consolidated Copper Co.

Wickes had become engineer in the office of Seeley W. Mudd and Philip Wiseman before World War I. Following the war, in which Wickes served as major of U. S. Engineers in France for two years, he returned to the organization. After discharge from the Army, in which for many years he continued his interest, he inspected the property of the Cyprus Mines Corp., discovered in 1913 by Charles Godfrey Gunther, and also investigated other properties in Southern Europe and the Near East.

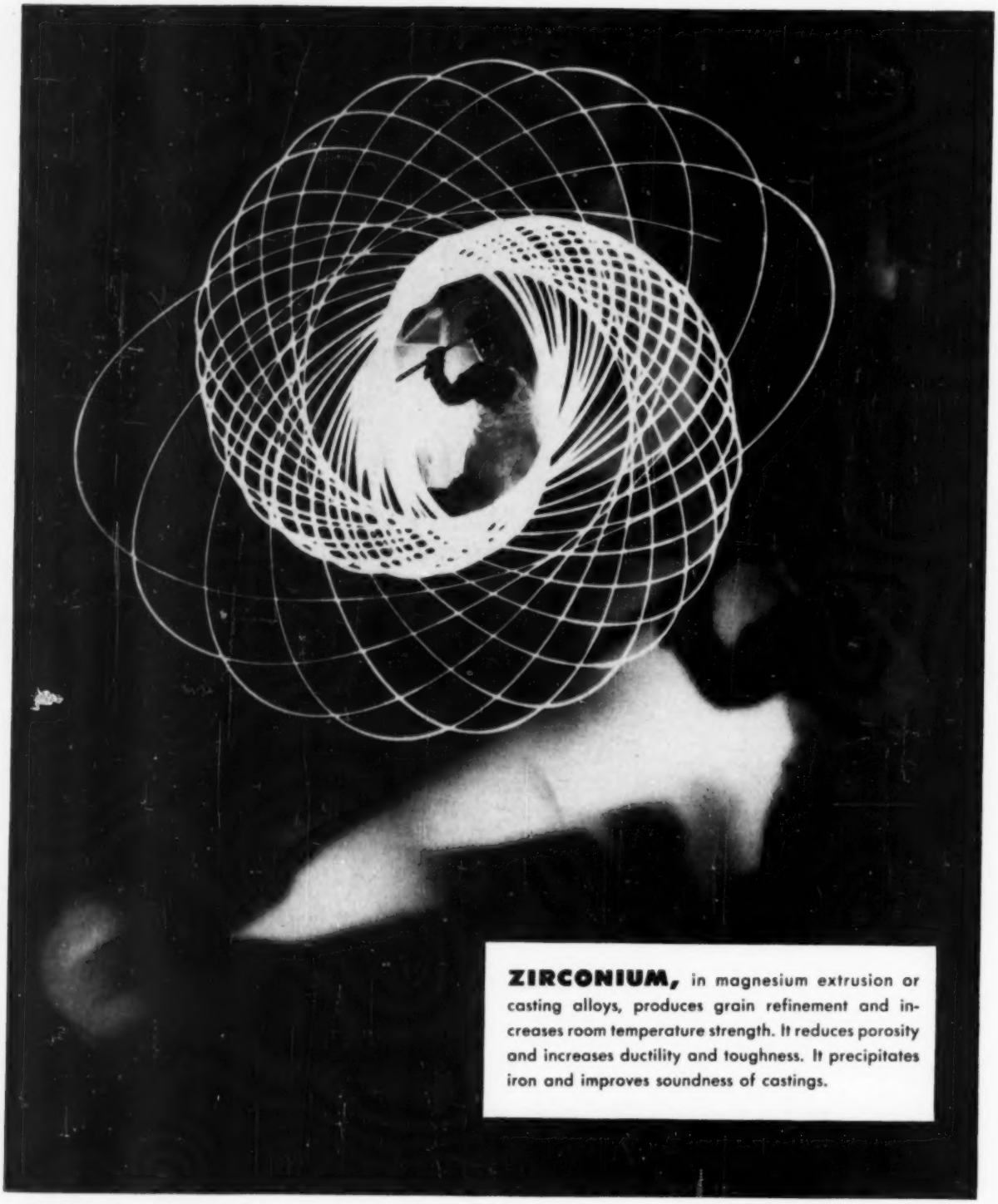
During his association with the Mudd-Wiseman group, Wickes examined many mining properties in the western states and Mexico. This association continued to his death and he served faithfully, honestly, fearlessly, in an advisory capacity on many projects and problems, as treasurer of Cactus Mines, as treasurer and director of Cyprus Mines Corp. He was well acquainted with the petroleum industry.

He was a Legion of Honor Member of the AIME, member of the Mining & Metallurgical Society of America, of the Society of American Military Engineers; the American Petroleum Institute, University Club of Los Angeles, the Masonic Order, the Shrine.

His counsel was highly valued by his associates; he was beloved for his keen sense of humor, his forthrightness, his sincerity, his high sense of loyalty to friends and profession and the thoroughness with which he pursued his business and his hobbies. He will be sorely missed.

NECROLOGY

Date Elected	Name	Date of Death
1913	Edson S. Bastin	Oct. 9, 1953
1920	C. F. Bowen	Unknown
1921	M. G. Cheney	Sept. 28, 1953
1948	B. C. Colcord	Aug. 16, 1953
1899	Robert J. Grant	Unknown
1945	Frederick Ernest Hall	Oct. 19, 1953
1905	C. E. Julihn	Aug. 8, 1953
1940	T. S. McDougal	Mar. 28, 1953
1941	Robert L. McLaren	June 29, 1953
1918	B. C. Osler	March 1952
1947	Richard W. Parsons	Oct. 5, 1953
1946	J. C. S. Reynolds	Unknown
1898	H. C. P. Woolmer	Oct. 11, 1953



ZIRCONIUM, in magnesium extrusion or casting alloys, produces grain refinement and increases room temperature strength. It reduces porosity and increases ductility and toughness. It precipitates iron and improves soundness of castings.

"TAM"* FUSED SALT (Potassium Zirconium Tetrachloride) is used in large quantities in extruded magnesium alloys and in casting alloys free from rare earth additions.

"TAM"* also offers a new ***Master Zirconium*** Alloy containing approximately 32% Zirconium for use in magnesium castings containing rare earth additions.

Write to us at our New York City address for details.

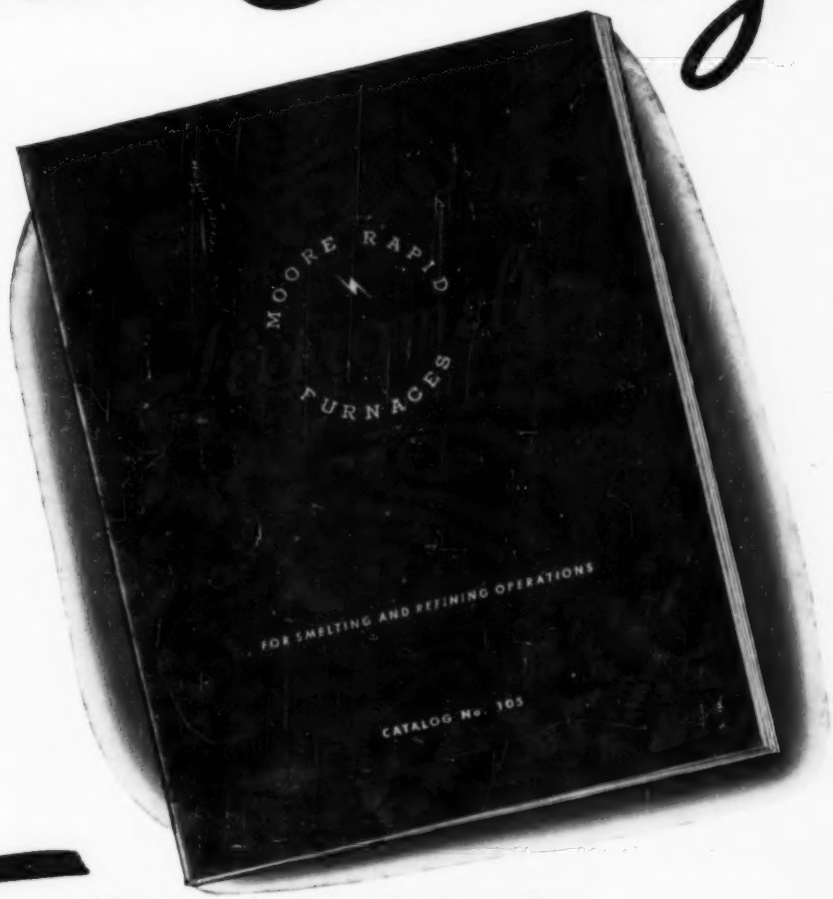
*TAM is a registered trademark.

TAM PRODUCTS
Registered U. S. Pat. Off.

TITANIUM ALLOY MFG. DIVISION
NATIONAL LEAD COMPANY

Executive and Sales Offices: 111 BROADWAY, NEW YORK CITY
General Offices, Works and Research Laboratories: NIAGARA FALLS, N. Y.

New Catalog



Furnaces . . .

For smelting ore and concentrates of copper, nickel, iron, magnesium, cobalt, antimony, manganese, zinc, lead, tin, barium, beryllium, etc.

For production of ferroalloys, carbide, phosphorus, cast refractories, etc.

For melting of metallics and nonmetallics.

This catalog is free! Get one for your files by writing the Pittsburgh Lectromelt* Furnace Corporation, 326 32nd Street, Pittsburgh 30, Pennsylvania. Request Catalog No. 105.

Manufactured in . . . CANADA: Lectromelt Furnaces of Canada, Ltd., Toronto 2 . . . ENGLAND: Birlec, Ltd., Birmingham . . . FRANCE: Stein et Roubaix, Paris . . . BELGIUM: S. A. Belge Stein et Roubaix, Bressoux-Liege . . . SPAIN: General Electrica Espanola, Bilbao . . . ITALY: Forni Stein, Genoa. JAPAN: Daido Steel Co., Ltd., Nagoya

*REG. T. M. U. S. PAT. OFF.

WHEN YOU MELT... MOORE RAPID *Lectromelt*

PROGRESS REPORT ON NATIONAL CARBON TRADE-MARK BLAST FURNACE LININGS

One out of every three blast furnaces in this country is now lined with "National" carbon. With this outstanding acceptance of carbon as a blast furnace refractory, let's take a look at its remarkable performance over the long haul.

Here are the facts:

- 23 "National" carbon-lined furnaces have each produced over 2 million tons.
- 5 of these have passed the 2½ million ton mark.

These are all original linings — *and still going strong!*

Every year more "National" carbon goes in... more unit tonnages go up and costs come down... more operators learn what *smooth* operation really is.

The term "National" is a registered trade-mark of Union Carbide and Carbon Corporation

NATIONAL CARBON COMPANY
A Division of Union Carbide and Carbon Corporation
30 East 42nd Street, New York, 17, N. Y.

District Sales Offices: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco

IN CANADA:
National Carbon Limited—Montreal, Toronto, Winnipeg

NATIONAL CARBON PRODUCTS

CARBON LININGS FOR FERRO-ALLOY FURNACES • CARBON MOLD PLUGS • GRAPHITE THERMOCOUPLE SHEATHS • GRAPHITE STARTERS FOR HOT-TOPPING • CARBON CINDER NOTCH PLUGS • GRAPHITE AND CARBON CORES • GRAPHITE RISER RODS • CARBON BOXES AND GRAPHITE POWDERS FOR HEAT-TREATING • PIPE AND FITTINGS • CARBON BRICK • PUMPS • CONDUCTOR ROLLS • SPECTROSCOPIC ELECTRODES • STEAM JETS • ANODES